Integrating indigenous knowledge systems into indigenous agricultural and industrial water management that impacts changes in riverine biodiversity: A conservation perspective

BY

SIBONELO THANDA MBANJWA

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DEDICATION

I wish to dedicate this thesis to my family. They have been a pillar and strength throughout my life. We have been through lot of challenges. I want to express my sincere thanks and love to them and will remain forever grateful for their love and support.

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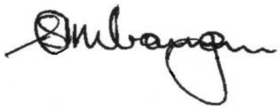
DECLARATION

I, Mr. Sibonelo Thanda Mbanjwa, Student number 45744181, identity number 86082559930083, hereby declare that this is my original piece of work. Where alluding to other works in the field, I have indicated those in the normal standard way of acknowledgement.

To the best of my knowledge, I have not committed any plagiarism or deliberate omission in the acknowledgement of the original works of others.

Signed at ....**DURBAN**..........................on this ..**30TH** ...day of.....**JULY**.......(month) 2017



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Signature: Sibonelo Thanda Mbanjwa

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Supervisor: Professor M. Coopoosamy

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Summary

Lower reaches of rivers as well as estuaries are regarded as South Africa's most productive ecosystems due to the important functions such as providing nursery areas and feeding sites for juvenile macro-invertebrate and fish species they perform. Furthermore, ecologically healthy estuaries are not only of critical importance since they facilitate the provision and recirculation of nutrients, they also provide conduits for fish migrations into the fresh water system and act as buffers during floods. In South Africa, these functions are continuously being threatened by residential and/or industrial developments. It is thus essential to determine the ecological integrity (structure and function) of these systems. An Ecological integrity study was carried out on the selected rivers in Kwazulu Natal between 2015 and 2017. This study was assessed in terms of selected abiotic drivers on specific biological responses.

The study was carried out according to the guidelines of the ecological determination methodologies and the resource directed measures for aquatic resources as set out by the Department of Water Affairs and Forestry, South Africa. Surveys were carried out during summer and winter seasons. Abiotic and biotic monitoring was carried out at four sites along each estuary. The abiotic component such as sediment composition and physio-chemical properties of the water was analyzed using standard methods. The biotic and abiotic components were analyzed using various indices, where applicable. The ecological integrity of the system can be accessed on the basis of its ability to carry out its natural functions. Results showed the various anthropogenic activities in the upper reaches of each river contributed to the high modified state of some of these rivers' unacceptable water quality, loss and/or modification of habitat and an altered hydrological pattern due to impacts by agricultural, industrial and domestic uses. The ecosystem services of the lower areas of the rivers under investigation are used extensively through sugarcane agricultural activities and heavy industries works inclusive of sand mining and rural sewage-treatment. These activities affect the ecological integrity of the rivers and ultimately the estuaries. This study aimed at determining the current state of ecological integrity of five selected rivers in KwaZulu Natal and to establish trends between current and historical periods for the evaluation of changing trends in ecological integrity. Abiotic and biotic indicator components were used to ascertain changes in the surrounding environment as well as to determine the ecological integrity of

these rivers. Monitoring of water quality, sediment grain size, moisture and organic content as well as habitat state, macro-invertebrates and fish assemblages was undertaken.

The following variables water temperature, chemical oxygen demand (COD), electrical conductivity (EC), pH and total alkalinity (TAL) as well as salts, nutrients and toxics were investigated to provide indications as to the state of the water-quality of these rivers. The Target Water Quality Requirements (TWQR) as developed by the Department of Water Affairs and Forestry for domestic use (Volume 1) and Aquatic Ecosystems (Volume 7) were used to evaluate the quality of the water sampled in this study. Historical data obtained from previous studies of similar study areas have also been evaluated. Sediment analyses were performed according to the protocol set out by the United States Environmental Protection Agency.

As a result of the abiotic drivers, results showed that the invertebrate reside in modified state. Physio-chemical, geomorphological and hydrological changes in this system resulted in the rivers' suffering a loss in both biological and ecological function as well as aesthetic value. It is apparent from the above that there is not a need for rehabilitation but also a need for effective and continuous management strategies. These strategies can only be successful if the bio-monitoring of the system includes the effects at both economical and social levels. The water quality of the rivers under this investigation was found to be in a slightly modified state with the majority of water quality parameters falling within the target values. Water quality parameters of the lower Thukela River, not within the required target, was highly elevated and could possibly cause negative impacts on the river functionality. The water quality parameters of Umvoti river, Umdloti river and uMngeni river were seriously modified. The sediment clearly indicated that the organic content of the all the rivers was low and directly relating to the possibility of erosion and transportation taking place in the Rivers. The removal of riparian vegetation by agricultural activities, sand mining and water abstraction contributed to the destruction of the habitats along all these rivers.

The South African Scoring System, version 5 (SASS 5), the Macro-invertebrate Response Assessment Index (MIRAI) and multivariate statistical analyses were implemented in order to determine the ecological integrity of the rivers. Results revealed that the SASS 5 integrity classes were generally one class higher than the integrity classes of MIRAI. The Fish assemblage methods used to determine fish samples included electro-narcosis and a 5m wide 12mm meshed seine net.

Impacts on the ecological integrity of the Rivers under investigation have been assessed by various sources. To protect the current ecological integrity and further destruction of the rivers under investigation, direct involvement by the relevant authorities is of paramount importance.

Key words: Amatikulu River; Ecological integrity; Thukela River; Umvoti River, Umfolozi River, uMngeni River

CHAPTER 1

STUDY MOTIVATION AND DESCRIPTION OF THE STUDY AREA

1.2 STUDY MOTIVATION

1.2.1 Introduction and literature review

Water is known to have a major influence on economic and social development in many countries (Vörösmarty *et al.*, 2010). However, Freshwater resource is becoming a scarce commodity, although it is essential in providing the environment with diverse freshwater ecosystems which offer valuable services and good such as Food, waste assimilation, industrial utilization, recreation and fisheries. This need by man is represented as benefits termed as ecosystem services (DWAF, 2009; UNEP, 2009). Aquatic ecosystems contribute directly and indirectly to economic and social development for human wellbeing by providing the necessary resources in terms of food, water provisions and at times transportation (Costanza, 2008; DWAF, 2009; O'Brien, 2011). This very ecosystem is being threatened by various human activities resulting from its indiscriminate utilization (Arthington *et al.,* 2010; Vörösmarty *et al*., 2010).

The ecosystem services of the lower regions of many of KwaZulu Natal Rivers are used extensively through sugarcane agricultural activities, heavy industries including sand mining and rural sewage-treatment works which ultimately impacts the ecological integrity of these rivers

Along the extensive coastline of South Africa, approximately 750 outlets (estuaries) to the sea can be found of which about only 250 functional estuaries still exist today. These estuaries make up about 70 000 ha of South Africa's most productive, yet threatened habitats (Turpie *et al.,* 2002). According to Huizinga and van Niekerk (2002), many estuaries in South Africa are of high ecological importance and often are the hub of tourism and residential developments and are therefore considered major assets of the country. Many of them are, however, under great pressure due to the surrounding socio-economic developments and it is essential that the principle of sustainable development be applied to estuarine environments with utmost care.

Estuaries are well known for their biodiversity, productive fish and invertebrate communities. They provide nursery areas for marine fish, conduits for ocean fish species and feeding and /or resting sites for significant populations of migratory birds (Turpie *et al*., 2002). They also support a number of endemic species which depend on estuaries for their survival. Furthermore, estuaries serve as important conduits for the transportation of sediments and nutrients into the marine zone (Turpie, 2004).

According to Huizinga and van Niekerk (2002), the severest impact on many estuaries is because of the reduction in the flow of river emanating from a variety of factors. It is well known that South Africa is a semi-arid country with relatively low rainfall which results in low mean annual run-off. Furthermore, due to this low rainfall, a decrease in flow of river together with an increased demand due to population growth will have added negative impacts.

Whitfield *et al.* (2000) argued that the degradation is due to other anthropogenic influences such as catchment degradation that, in turn, causes excessive siltation in estuaries, fresh water deprivation especially where minor flood events is captured by river dams, agricultural, residential and/or industrial developments encroaching onto estuarine floodplains, water pollution, including nutrient enrichment, arising from harmful agricultural, aquaculture, industrial or residential activities, over exploitation of fish and bait resources, poor management, lack of education and unclear legislation. Essential monitoring of this valuable resource is of vital importance.

1.1.2. Monitoring

Monitoring can be by observation of physical changes or based on environmental factors. The environmental factors are constantly changing due to the ever changing climatic conditions. The environmental monitoring of these climatic changes should be coupled with the monitoring of other physical and geographical attributes such as air, water, soil and biotic and abiotic factors (Artiola *et al.*, 2004; Weston, 2011; Glaholt *et* al 2012). This will help establish historical data and aid in averting drastic changes that may occur due to adverse weather changes. It will also form a basis to inform legislature on decision-making and future corrective measures to undertake (Hohls, 1996; Kleynhans, 2003; Mitchell, 2002; Davis *et al.*, 2010; Weston, 2011). The ecological driver is often the abiotic components whereas the biotic components are often termed the ecological responder components which are relatively good indicators of ecosystem health due to their sensitivity to a low level of disturbance of a wide variety of environmental impacts and their adaptability and resilience thereof (Roux, 1999; Todd and Roux, 2000; Weston, 2011). It is therefore very important to corroborate both the abiotic and biotic together when determining the ecological health of aquatic ecosystems (Hohls, 1996).

Environmental monitoring can generate large amounts of data due to the fact that it includes various components of abiotic and biotic lines of evidence. This makes it difficult to simplify the amount of data to such a point where it is useful to resource managers, conservationists, politicians and the general public (Hohls, 1996). These factors can be derived from a number of rapid assessment techniques by which abiotic and biotic lines of evidence community metric measures can be numerically presented. These community metric measures are used to quantify the status of aquatic ecosystems by summarizing the data on the present ecological health or integrity status of aquatic communities of rivers compared to natural or near-natural reference conditions (Hohls, 1996; Van Eeden, 2003; Kleynhans *et al.,* 2005).

1.1.3. Abiotic drivers

1.1.3.1. Water quality

DWAF (1996) stated that water quality is the physical, chemical, biological and aesthetic characteristics of water which determine its fitness for a variety of uses and the integrity of the aquatic system. Water is a medium where many biotic components reside. The indication of a poor system is when there is a drastic reduction in the biotic component of the water body. The monitoring of water quality is thus essential in determining the integrity of an ecosystem (Munn *et al.,* 2002). Some of the variables that determine water quality include temperature, dissolved oxygen, salts, pH and turbidity as well as nutrients such as phosphate, nitrite and nitrate. The monitoring of inorganic substances such as mercury (Hg), copper (Cu) and ammonium ions (NH_4^+) as well as organic substances which include phenol and atrazine will determine the toxicity of the water body and determining the total dissolved solids and electrical conductivity will provide an indication of the non-toxic inorganic substances (DWAF, 1996a; 1996b; Ramollo, 2008).

1.1.3.2. Sediment

The sediments within a rivers system is of critical importance. Rivers carry these sediments as suspended particles which settle in estuaries. These suspended particles are the food for organisms residing in the river system (USEPA, 2001; IAEA, 2003; Charkhabi *et al.*, 2008). Fish species also use these areas for spawning as well as rearing (USEPA, 2001; Goode *et al.,* 2012). The analysis of these sediments is an important factor when conducting environmental monitoring programmes in a river ecosystem (Roux *et al.*, 1993; Charkhabi *et al.*, 2008). This analysis can provide the level of contamination of a river system while serving as a reservoir for pollutants.

The International Atomic Energy Agency (IAEA) (2003) reported that analyses of sediment grain size are used to characterize the physical characteristics of sediment. The grain sizes influence both chemical and biological variables and can therefore be used to normalize chemical concentrations according to sediment characteristics accounting for some of the variability found in biological assemblages (IAEA, 2003). The type of grain size can also provide information on the amount (based on particle size) of sediment that is being transported down to a river (DiToro *et al.*, 1991; Venter and Van Vuren, 1997).

1.1.3.3. Habitat

The habitat is important for survival of resident species and changes in such habitats will result in invasion of alien species. The survival of the biota in an ecosystem is directly dependent on the habitat composition (Malherbe, 2006; Carminati, 2008). Habitat types of rivers include pools, rapids, sandbanks, bedrock, boulders, cobbles, gravel, sand, mud, runs, riffles as well as marginal and aquatic vegetation (Malherbe, 2006). The diversity of the in-stream habitat is influenced by the type of substrate available. The naturally occurring poor rivers will have low diversity (Mangold, 2001; Malherbe, 2006). The riparian vegetation provide habitats for aquatic and terrestrial species and perform several ecological functions which ensure that an aquatic ecosystem stays healthy (Mangold, 2001; Malherbe, 2006).

1.1.4. Biotic drivers

1.1.4.1. Macro-invertebrates

According to Álvarez-Cabria *et al*. (2010), macro-invertebrates are one of the most important organism groups used to evaluate the ecological integrity of rivers. Macro-invertebrates include aquatic insects, larvae of insects with terrestrial adult forms, mussels, clams, snails and worms that are aquatic throughout their life cycle (Malherbe *et al.*, 2010). Aquatic macro-invertebrates are commonly used to assess the biological integrity of rivers and streams, more commonly than any other biota (O'Keeffe and Dickens, 2000; Thirion, 2007). Macro-invertebrate communities adapt to the flow conditions which control temperature, sediment transport and nutrient flows in a system (Thirion, 2007; Álvarez-Cabria *et al*., 2010). While macro-invertebrate communities are influenced by human activities their structure and composition change seasonally in different locations within a selected estuary (Álvarez-Cabria *et al*., 2010). Frequency of sampling and sampling at different seasons from a selected area within an estuary can reduce the potential of any disadvantage of using macro-invertebrate communities as ecological indicators (Álvarez-Cabria *et al*., 2010).

1.1.4.2. Fish

The presence or absence of fish population can provide valuable information on the ecological diversity of a river (Maceda-Veiga and De Sostoa, 2011). It is thus advantageous to use fish as environmental indicator as they are widely distributed in aquatic environments, have diversity of functional guilds, play major ecological role in food webs, their relatively long life-span which accounts for long-term effects and their value for mankind as food source (DWAF, 1999; Whitfield and Elliott, 2002; Van der Oost *et al.,* 2003; Harrison and Whitfield, 2004; Cabral *et al.,* 2012; Gamito *et al.,* 2012). The disadvantages include the high mobility of fish not restricting to a specific area, their high tolerance to contaminates and physical degradation of habitats as well as the selective nature of sampling gears required for large sampling efforts (Whitfield and Elliott, 2002; Harrison and Whitfield, 2004; Cabral *et al.,* 2012; Gamito *et al.,* 2012).

1.1.5 Study Area

1.1.5.1 uMngeni River

The uMngeni River is located in KwaZulu-Natal, South Africa. Its GPS coordinates are: Latitude: 29º48′36″S, Longitude: 31º02′08″E. The river originates from Dargle, a small farming village on the outskirts of Howick in the KZN midlands, and its mouth is located in the Indian Ocean, Durban (Figs 1.1 and 1.2). The river is 232 kilometres long, with a catchment area of 4 432 kilometres. The uMngeni River boosts some of the famous waterfalls, known as the Howick Falls. There are reports that suggest that agricultural industries impact on the river's health due to excessive nutrient inputs they introduce into the river streams (DWAF, 2017).

The Palmiet River is a tributary of the uMngeni River with a small catchment of $37km^2$ and is found some 15km northwest of Durban, Kwa-Zulu Natal (du Preez and de Villiers, 1987). The source of the river is situated in Kloof and flows through the Pinetown industrial area, the Westville and Reservoir Hills' residential area and enters the uMngeni River in the vicinity of Springfield Flats (du Preez and de Villiers, 1987). The river is influenced by industrial, human and partial agricultural pollution. The topography near the Pinetown basin is relatively flat but majority of the area is undulating with deep gorges in the Palmiet Nature Reserve that have been well dissected by the river (du Preez and de Villiers, 1987).

Fig 1.1: Map of uMngeni River (Google Maps)

Fig 1.2: Picture of uMngeni river from M4 bridge upwards

1.1.5.2. Thukela River

The Thukela River originates from the Drakensberg Mountain Range above Bergville and ends approximately 95 km north of Durban into the Indian Ocean (DWAF, 2001) (Figs 1.3 and 1.4). The lower reaches of the Thukela River catchment are influenced by sugarcane agricultural activities, industry (Mandini, Sappi Mill) which are direct drives to the loss of natural habitat, erosion and siltation (Stryftombolas, 2008). The Sappi Tugela Mill discharges its effluent directly into the Thukela River close to its confluence with the eMandeni River. The eMandeni River supports the Isithebe rural area and industrial complex and rural sewage treatment works from both Isithebe and Mandini. Previous studies on the lower reaches of the Thukela River have been done by Oliff (1960), Brand *et al.* (1967), Coke (1995), De Moor *et al.* (1999), DWAF (2001a), DWAF (2003), Cloete *et al.* (2008), Ferreira *et al.* (2008); Stryftombolas (2008) and O’Brien (2010a).

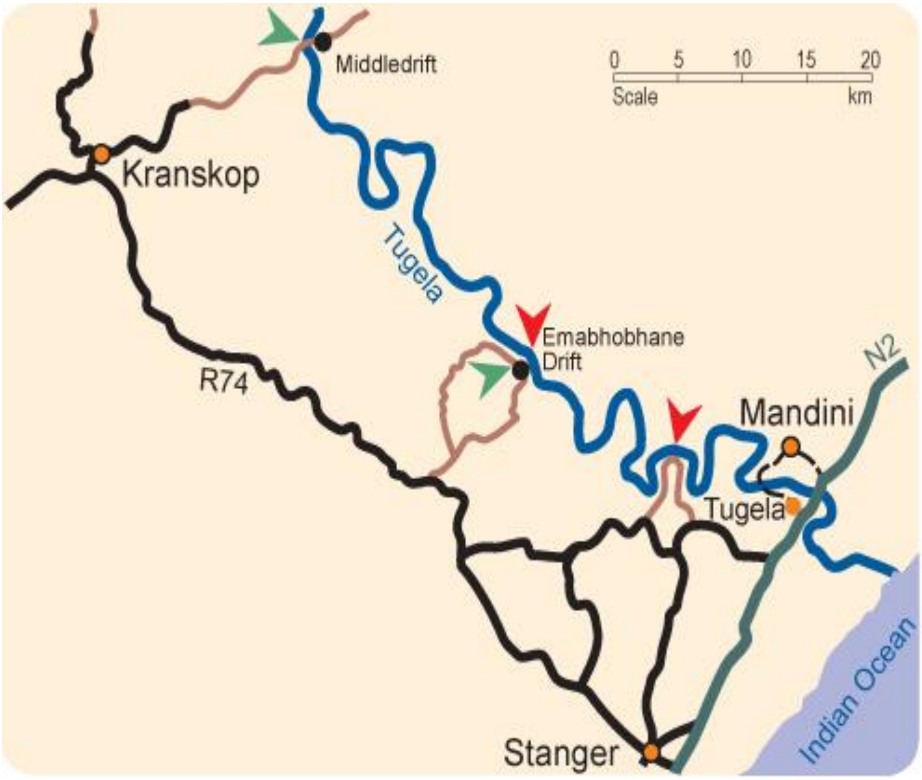

Fig 1.3: Map of Tugela River (Google images)

Fig 1.4: Picture of Tugela River from N2 Bridge upwards

1.1.5.3 Umvoti River

The Umvoti River originates from the Natal Midlands and enters the Indian Ocean near Blythedale Beach about 90 km north of Durban DWAF (2004a) (Figs 1.5 and 1.6). The lower reaches of the Umvoti River are influenced by sugarcane agricultural activities, heavy industries, informal settlements, rural areas as well as rural sewage-treatment works. Overgrazing and water abstraction for agricultural, commercial and industrial uses have been observed in the lower reaches of the Umvoti River (Carminati, 2008).

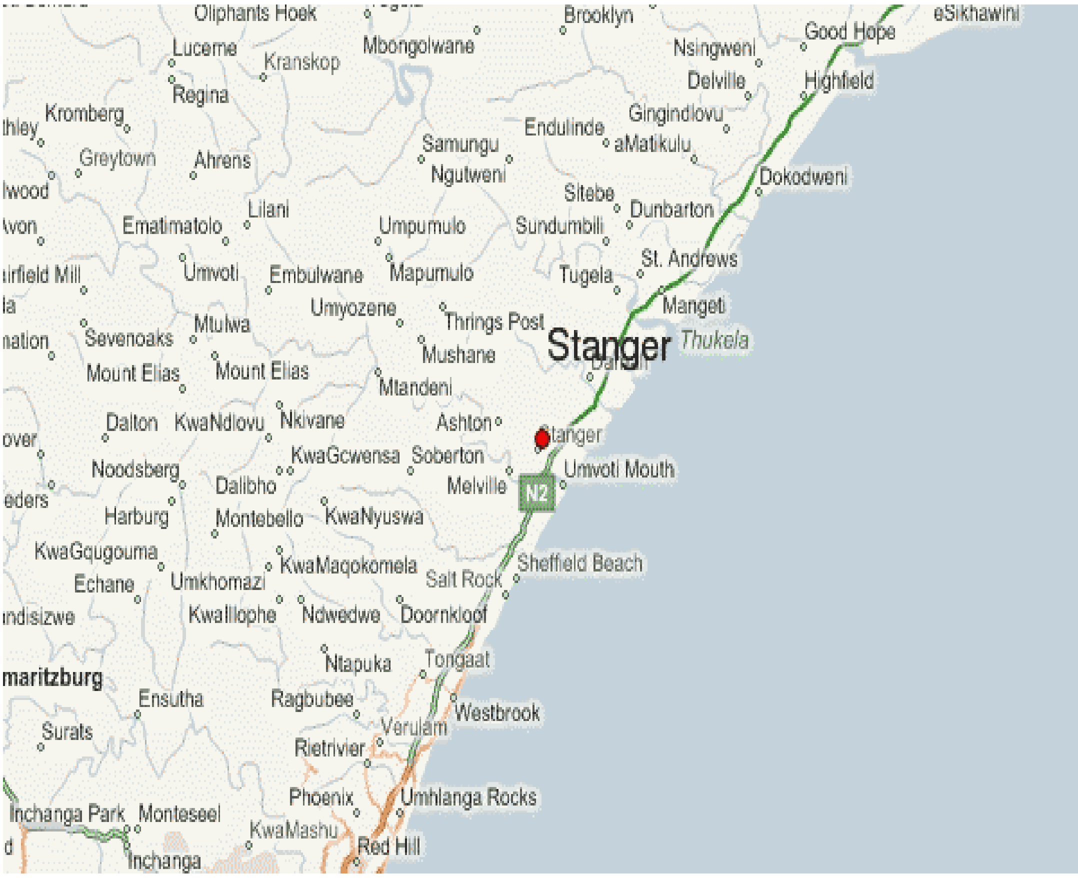

Fig 1.5: Map of Umvoti River (Google Maps)

Fig 1.6: Picture of Umvoti River from N2 bridge downwards Fig 6.

1.1.5.4 Umdloti River

The Umdloti River flows in the area near Verulam in the KwaZulu-Natal province, South Africa. The mouth of the Umdloti River is situated north of Durban. The name Umdloti is the Zulu word for a species of wild tobacco that grows there. The river is closely associated with the new King Shaka International airport as well as many industries that are located in the Verulam area (Figs 1.7 and 1.8). The river is heavily sand mined at the mid to lower reaches of the river.

Fig 1.7: Map of Umdloti River (Google Maps)

Fig 1.8: Picture of Umdloti River above sand Mining site

1.1.5.5 Umfolozi River

Umfolozi River is situated in KwaZulu-Natal, South Africa. It originates from the formation of two sister rivers called the black and white Umfolozi Rivers near the South-Eastern boundary of the Hluhluwe-Umfolozi Game Reserve (Figs 1.9 and 1.10). In Zulu translation, the name Umfolozi, describes the zigzag nature of the river. The GPS coordinates of the river are Latitude: 28º23′32″S, Longitude: 32º25′27″E. The river follows an easterly direction towards the Indian Ocean, and its mouth is located at Maphelana. The river assists sugarcane farming community and provides shelter for abundant species located at St Lucia Estuary (Fig 1.9). Furthermore, the Umfolozi catchment is used for subsistence agricultural practices including dry-land agriculture comprising livestock grazing and rain fed agriculture (Tefangenyasha *et al.*, 2010).

Fig 1.9: Map of Umfolozi River (Google maps)

Fig 1.10: Picture of Umfolozi River near mouth region

In this dissertation, the ecological integrity of selected river estuaries was undertaken consequential to its being influenced and impacted by various anthropogenic activities over time. The rivers were selected based on the increasing impacts of industries, agriculture and human activities for some years. It is, therefore, crucial to determine the extent to which deteriorating water quality affects the ecological integrity of these estuaries. All investigations were undertaken from the estuaries to 10km up stream for selected rivers in KZN. The flood zone vegetations were also sampled to ascertain the composition and biodiversity of each river. Alien vegetation and other species were noted and mapped accordingly for conservation purposes. Industries associated with these rivers were also noted. The type of effluents from each industry were noted and analyzed for chemical content.

1.2 Study Hypothesis

River estuaries have suffered a loss in its ecological integrity due to chemical, geo-morphological and hydrological changes caused by industrial, agricultural and urban activities upstream of the estuaries

1.2.1 Aims:

The aim of this research is in two folds:

1. To determine the ecological integrity of biotic and abiotic components of the selected rivers in KZN
2. To develop management protocols that can be followed to facilitate effective management of river systems throughout the province of KZN for conservation purposes.

1.2.2 Specific objectives include:

1. To identify the impacts of the activities of the farming communities along selected rivers in KZN.

2. To identify the effects of the activities of all industries associated with the selected river systems of major rivers in KZN.
3. To examine the traditional knowledge systems that communities used to cope during adverse situations
4. To establish ways to integrate indigenous knowledge into improving water management and conservation during adverse weather conditions

1.2.2.1 Sub Objectives

- To identify heavy metals in river water from different sampling sites.
- To sample the fluvial system at specific sampling sites, reflective of land use changes in the catchment, for the following variables: water and sediment.
- To determine and compare the heavy metal concentrations in water and sediment samples from each river during summer and winter periods.
- To assess the impacts of agricultural and industrial activities on the water quality of each of the rivers
- To assess the ecological integrity of selected rivers in KZN

1.2.2.2 The sub questions are:

- What are the various land uses associated with the river system?
- How do industries and agriculture contribute to the heavy metals in the river?
- What are the levels or concentrations of the heavy metal in the water and sediment?
- What is the contribution of the various land use areas to the water quality?
- What is/are the effects of seasonal changes on the concentration of heavy metals in each river?
- What was the level of heavy metals in the river in previous years?
- How do the heavy metal concentrations impact ecological integrity along rivers in KZN

CHAPTER 2

Assessment of the present ecological integrity of selected driver components (water quality, sediment and habitat) of the uMngeni, Thukela, Umvoti, Umdloti and Umfolozi Rivers, KwaZulu-Natal

2.1. Introduction

The integrity of all rivers is based on the abiotic and biotic components that exist within the river system. These components are often termed driver and responder. The driver is the abiotic component. A change in the driver will have a corresponding impact on the responder component (biotic component). Monitoring of these components is of paramount importance to maintaining the integrity of the river for future generations. The changes in these components will require immediate intervention to prevent any loss of biodiversity (Artiola *et al.*, 2004; Wiersma, 2004; Weston, 2011). Driver or abiotic components include water quality, sediment grain size, moisture and organic content as well as habitat state whereas responder or biotic components involve macro-invertebrates and fish assemblages (Munn *et al.*, 2002). The sediment analyses provide information and indications of any pollution in the system that may result in increased toxicity of the system (IAEA, 2003; Charkhabi *et al.*, 2008). Sediment forms part of an integral component of aquatic ecosystems as it provides habitat, feeding, spawning and rearing areas for numerous aquatic organisms (USEPA, 2001). Sediment analyses are directly linked to the habitat occurring in a specific area. The habitat changes are resultant of any change that may be related to the sedimentation of that particular area (Uys *et al.*, 1996). When the habitat diversity is extensive and un-impacted, the biotic community structures tend to be good.

This chapter addressed the assessment of the current ecological state of the selected driver components of the uMngeni, uThukela, Umfolozi, Umdhloti and Umvoti Rivers, KwaZulu-Natal .

2.2. Materials and methods

2.2.1. Site selection and sampling (Table 2.1)

The investigation centered on the lower reaches of each of the selected rivers. These are catchment areas that could provide a perfect indication of the sedimentation and the involvement of the contributors to the quality of the sedimentation. Similar studies have been conducted in the lower reaches of the Amatikulu, Thukela and Umvoti Rivers in KwaZulu-Natal, South Africa (CRUZ , 2000; O'Brien *et al*., 2005; Malherbe, 2006; Schüring and Schwientek, 2006; Carminati, 2008; Ferreira *et al.,* 2008; Malherbe *et al.,* 2008; Stryftombolas, 2008; Swemmer, 2008; O'Brien *et al.*, 2009; O'Brien, 2010; O'Brien, 2011). These previous investigations suggested that agriculture, industry, human domestic use and rural sewage treatment works had major influences resulting in the deterioration of the river systems. Depending on the seasonal variations as well as the tidal levels, the changes in various drivers have been noted to cause most damaging at the low tidal periods.

Table 2.1: Site co-ordinates for study area for each river under investigation

	GPS Coordinates of sample sites									
	uMngeni		**uThukela**		**Umdloti**		**Umfolozi**		**Umvoti**	
	Lat	**Long**	**Lat**	**Long**	**Lat**	**Long**	**Lat**	**Long**	**Lat**	**Long**
Site1	-29.8183	31.01171	-29.06567	31.24711	-29.3917	31.6970	-28.2331	32.3426	- 29.28979	31.29331
Site2	-29.0899	31.01347	-29.19342	31.47353	-29.4011	31.6567	-28.1975	32.3112	- 29.28108	31.10988
Site3	-29.1665	31.1431	-29.08781	31.30017	-29.3819	31.5439	-28.2745	32.3984	- 29.36998	31.30013
Site4	-29.0995	31.1363	-29.1690	31.39765	-29.3954	31.5995	-28.1856	32.2997	- 29.35762	31.31012
Site5	-29.7074	31.0548	-29.09971	31.36501	-29/3673	31.6548	-28.2120	32.2341	- 29.36566	31.30981

Lat = Latitude

Long = Longitude

2.2.1.1 Water quality

To determine the state of water quality, the following variables were selected:

1. Temperature
2. Chemical oxygen demand (COD)
3. Electrical conductivity
4. pH and total alkaloids
5. Nutrients and toxics

This determination was adopted from previous investigations by Carminati (2008), Stryftombolas (2008), O'Brien *et al*. (2009) and Malherbe *et al*. (2010) for assessing the physicochemical variables.

2.2.1.2 Sampling protocol

Samples were collected (sub-surface) in clean polyethylene bottles. Prior to sampling the bottles were rinsed with the water from the sample sites to eliminate contamination and eliminate error in sampling. The samples were then stored in a cooler box and transported to the laboratory at Mangosuthu University of Technology for further analysis.

During sampling, physical variables included temperature, pH, oxygen concentration and saturation levels and electrical conductivity were measured *in situ*. The physical variables were measured with an YSI professional plus multi-meter (water quality sampling and monitoring meter).

2.2.1.3 Laboratory analyses

The water samples that were collected were taken to the laboratory for the following analyses:

1. Chemical oxygen demand
2. Electrical conductivity
3. pH
4. Total alkalinity
5. Chlorides
6. Sulphates
7. Calcium
8. Sodium
9. Nitrates
10. Nitrites
11. Ortho-phosphates
12. Ammonium

To evaluate the quality of the sampled water, the Target Water Quality Requirements (TWQR) (DWAF, 1996a) for domestic use and Aquatic Ecosystems (DWAF, 1996b) were used (Table 2.2). A comparison was then done between all the rivers under investigation.

Table 2.2: Target water quality ranges for constituents as provided in the DWAF (1996a and 1996b) Guidelines for Domestic Use and Aquatic Ecosystems.

Variables	**Units**	**Abbreviations**	**Domestic use**	**Aquatic ecosystem**
Temperature	^oC	^oC	N/A	<2^{o}C, <10%*
pH		pH	6.0 – 9.0	>0.5 0r 5%*
Oxygen	mg/l	O_2	N/A	6 – 12mg/l
Oxygen	% Saturation	O_2%	N/A	80 – 120%
Conductivity	mg/l	EC	0 – 0.7mS/cm	N/A
Total alkalinity as $CaCO_3$	mg/l	TAL	0 – 8mg/l	N/A
Nitrates as N	mg/l	NO_3	N/A	N/A
Nitrites as N	mg/l	NO_2	N/A	N/A
Nitrogen ammonia as N	mg/l	NH_4	0 – 1 mg/l	<7µg/l
Soluble ortho-phosphate as PO_4	mg/l	PO_4	N/A	15%* and not change to trophic status
Chemical oxygen demand as O_2	mg/l	COD	N/A	N/A
Chloride	mg/l	Cl	100 – 200mg/l	N/A
Calcium	mg/l	Ca	0 – 32 mg/l	N/A
Sodium	mg/l	Na	100 - 200mg/l	N/A
Sulphate	mg/l	SO_4	0 – 200mg/l	N/A

***** = refers to maximum allowable change in variable from reference value.

2.2.2. Sediment

2.2.2.1. Sampling protocol

Sediment samples were collected at all proposed sites from all the rivers in this investigation. Samples were scooped from the catchment substrates and placed in polyethylene zip-lock bags and were kept frozen to prevent organic material digestion by invertebrates or other organic decomposition until analysis of the sediment characteristics was carried in the laboratory.

2.2.2.2. Sediment analyses

Analyses were performed according to the protocol set out by the United States Environmental Protection Agency (USEPA, 2001) as adopted from studies implemented by Carminati (2008), Stryftombolas (2008) and Malherbe *et al*. (2010). A known amount of sediments for each site was dried for a total of 4 days at 60°C and subsequently weighed to determine water quantity. The organic content of each sediment sample was determined by subjecting a known amount of sediment (accurate to 0.0001g) and incinerating it for a minimum of 6 h at 600°C. The samples were then once again weighed to determine the percentage organic content in the sample (Table 2.3). The remaining dried sediment was then used to determine the grain size of each sample by using an Endecott sieve system with various sieves ranging from >4 000 µm to 53 µm (Table 2.4).

Table 2.3: Organic content classification system in sediment (USEPA, 2001)

Classification	Percentage
Very low	<0.05%
Low	0.05 – 1%
Moderate low	1 – 2%
Medium	2 – 4%
High	>4%

Table 2.4 : Grain-size categories according to Cyrus *et al.* (2000)

Grain size in um	**Categories**
>4000 µm	Gravel
4000 – 2000 µm	Very coarse sand
2000 – 500 µm	Coarse sand
500 – 212 µm	Medium sand
212 – 53 µm	Very fine sand
<53 µm	Mud

2.2.2. **Habitat** (Table 2.5 and 2.6)

The habitat availability, diversity and state were assessed by means of the Integrated Habitat Assessment System Version 2 (IHAS v 2) which was adopted from McMillan (1998) and the Index of Habitat Integrity (IHI) which was adopted from Kleynhans (1996). The approaches set out by these two indices to assess habitat availability; diversity and state are widely implemented throughout the National River Health Programme. These indices were performed by entering various observations on a provided score sheet in the field. The values of the indices were then calculated and a rating system for each index was then used to describe the quality of the habitat of the different given site under study.

Table 2.5: Summary of the scoring procedures used to determine the Index of Habitat Integrity (IHI) (Dallas, 2005)

Impact class	Description	Score
None	No discernible impact / the modification is located in such a way that it has no impact on the habitat quality, diversity, size and variability	0
Small	The modification is limited to very few localities and the impact on habitat, diversity, size and variability is limited	1 – 5
Moderate	The modifications are present at a small number of locatlities and the impact on habitat quality, diversity, size and variability are fairly limited	6 – 10
Large	The modification is generally present with a clearly determinal impact on habitat quality, diversity, size and variability. Large areas are, however, not affected	11 – 15
Serious	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	16 – 20
Critical	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally.	21 - 25

Table 2.6: Habitat integrity classes for IHAS and description of each class, adopted from Kleynhans (1999)

Class	Description	Score (% of Total)
A	Unmodified, natural.	90 – 100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place, but the assumption is that ecosystem functioning is essentially unchanged	80 – 89
C	Moderately modified. A loss or change in natural habitats and biota has occurred, but basic ecosystem functioning appears predominately unchanged.	60 – 79
D	Largely modified. A loss of natural habitat and biota and a reduction in basic ecosystem functioning is assumed to have occurred.	40 59
E	Seriously modified. The loss of natural habitat, biota and ecosystem functioning is extensive.	20 – 39
F	Modifications have reached a critical level and there has been an almost complete loss of natural habitat and biota. In the worst cases, the basic ecosystem functioning has been destroyed.	0 - 19

2.3 Results and discussion

2.3.1 uMngeni River:

2.3.1.1 Chemical composition of the Umgeni River

South African river systems suffer from increase pollution caused by widespread industrialization, urbanization, afforestation and agriculture. Heavy metals have been reported on several studies as the major pollutant factors. Some of the common heavy metals that have been detected on South African river streams include Chromium (Cr), Lead (Pb), and Zinc (Zn) (Tables 2.7, 2.8 and 2.9). uMngeni river suffers from heavy metal pollution due to widespread industrial operations at borders (Dikole, 2014).

Table 2.7: Heavy metal concentration ranges of water samples collected in the uMngeni River (Dikole, 2014)

Heavy Metals	Concentration (μgL^{-1})
Cadmium (Cd)	1.0-6.0
Copper (Cu)	1.0-11.0
Chromium (Cr)	0.3-82.7
Zinc (Zn)	2.7-65
Lead (Pb)	0.3-16

Table 2.8: Total metal content of sediment samples collected in the uMngeni River (Dikole, 2014).

Heavy Metals	**Concentration (mg kg^{-1})**
Cadmium (Cd)	0.07-264.5
Copper (Cu)	11.9-168.5
Chromium (Cr)	28.6 – 135.1
Zinc (Zn)	29.5 – 602.1
Lead (Pb)	12.1 – 601.7

Table 2.9: South African river water and sediment guidelines (DWAF, 1996).

Element	DWAF value for river water/mg L^{-1}
Cadmium (Cd)	0.1500
Chromium (Cr)	0.0070
Copper (Cu)	0.0003
Lead (Pb)	0.0002
Zinc (Zn)	0.0020

The pH is a key indicator for ascertaining the concentration, accumulation, and bioavailability of metals in aquatic systems. It can also be used to indicate the presence of phosphates, nitrates and organic materials in freshwater (Serife *et al.,* 2001). Some of the important physical-chemical indicators that can be used to assess river streams amongst other things include Reduction-Oxidation potential, determination of the Dissolved oxygen (DO), Electrical conductivity (EC), and Salinity (Table 2.10) (Dikole, 2014).

Table 2.10: Physico-chemical parameters of the uMngeni River, from samples collected at different locations of the river (Dikole, 2014).

Site Code	Seasons	pH	Temp (°C)	Eh/mV	TDS (mgL^{-1})	DO(mgL^{-1})	EC (μScm^{-1})	Salinity/ (mgL^{-1})
A	Winter	6.02	14.8	80	440	11.2	860	0.2
	Summer	6.04	24.2	35	18	6	31.2	0
B	Winter	6.79	15.3	49	395	10.5	772	0.1
	Summer	6.84	26	74	26	6.6	45.4	0
C	Winter	6.47	16.4	73	396	9.6	774	0.1
	Summer	6.6	25.6	130	26	6.75	45.4	0
D	Winter	6.38	16.3	79	400	10.7	702	0.1
	summer	6.77	25.7	115	26	6.9	48.6	0
E	Winter	6.38	15	158	48	2	1000	0
	Summer	6.59	25.3	97	28	5.8	47	0
F	Winter	7.1	16.1	55	562	2.9	1269	0.3
	Summer	7.38	26.2	60	44	6.1	75.8	0
G	Winter	7.25	17.3	59	1594	3.7	5690	1.5
	Summer	7.47	26.3	58	88	6.6	151.7	0
H	Winter	6.6	15.4	44	820	1.2	1440	0.6
	Summer	7.24	24.4	8	69	6.6	118.5	0

A- Before Inanda Dam, B - After Inanda Dam 1, C - After Inanda dam 2, D - After Inanda Dam 3, E - Start of Industries, F - After Waste Management, G - End of Industries, H - Estuarine Site

Table 2.11: Current water quality data for uMngeni River under this investigation

Site	°C	O_2 (mg/l)	O_2 Satu	EC	pH	NO_2	NO_3	PO_4	N	Cl	TAL	Ca	SO_4	Na	COD
Site1W	17.1	9.45	93.1	284	7.55	0.97	0.55	0.04	0.05	41	35	10.1	3.43	39	88
Site1S	29.3	6.33	89.6	301	7.34	0.89	0.43	0.03	0.02	45	39	9.97	2.99	41	75
Site2W	19.2	8.95	86.3	210	8.12	1.45	0.61	0.02	0.07	37	28	6.33	4.10	36	95
Site2S	27.8	7.13	80.1	290	8.01	1.34	0.59	0.06	0.09	40	32	7.82	3.87	40	97
Site3W	17.9	9.44	90.2	195	7.23	0.91	0.12	0.05	0.07	33	47	11.0	5.55	41	56
Site3S	28.7	6.67	73.3	287	7.45	0.94	0.14	0.03	0.06	38	45	9.97	4.87	47	67
Site4W	18.5	8.61	44.6	212	7.10	1.25	0.19	0.07	0.02	44	38	10.3	3.64	36	100
Site4S	29.9	7.01	40.2	301	7.24	1.17	0.16	0.08	0.04	41	36	7.88	3.52	43	89
Site5W	17.7	8.99	50.1	184	8.11	0.87	1.10	0.14	0.05	29	41	6.43	2.97	38	85
Site5S	28.6	6.13	47.4	247	7.53	0.94	0.98	0.12	0.06	37	39	7.11	3.01	43	77

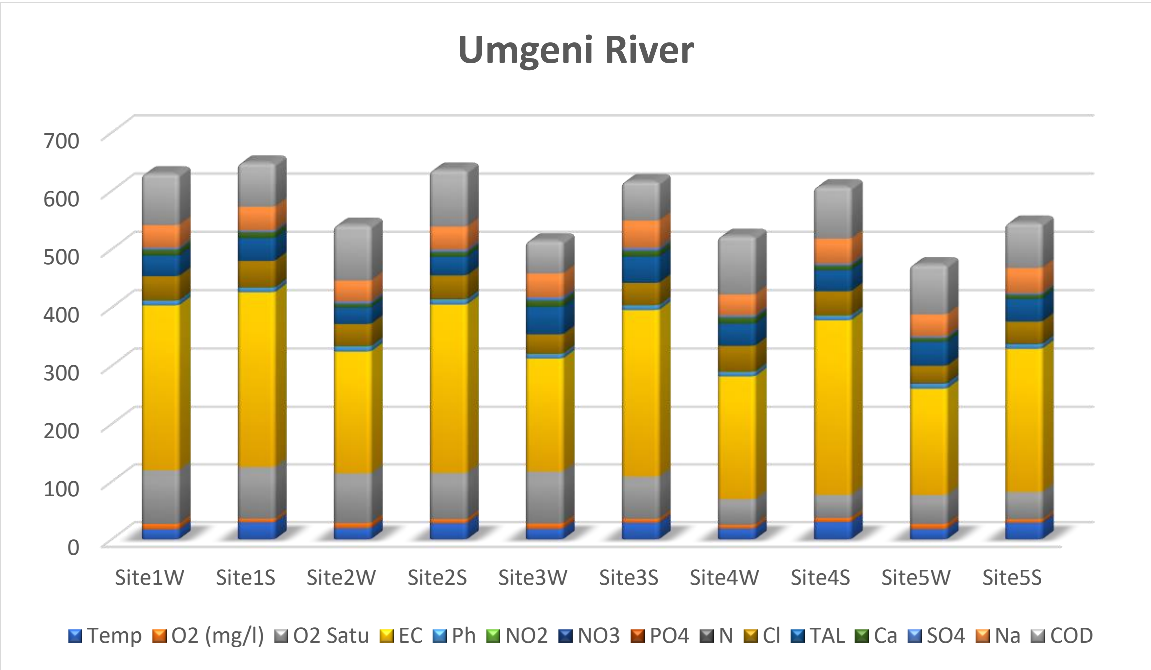

Fig 2.1: Stacked graph of the chemical composition of the uMngeni River

The temperature of the flowing water has been recorded to be lower during the winter months than the summer months. In most cases, the temperature of the water seems to be influenced by the environmental temperature as well as lower flow rate. This is in line with the seasonal fluctuations as indicated by Gallagher (1999). The temperature ranged from as low as 17.1 ^{0}C in the winter months to 29.9 ^{0}C in the summer months. However, there seem to be a gradual difference in temperature of approximately 10^{0}C between the seasons. Although seemingly small, the temperature difference had a marked impact on the organisms occurring in the river and ultimately affected the ecological biodiversity. According to DWAF (1996b), none of the temperature levels recorded during the current investigation on the lower reaches of the uMngeni River exceeded the TWQG for aquatic ecosystems.

The levels of the oxygen (mg/l) ranged from 6.13 mg/l to 9.45 mg/l (Table 2.11). Oxygen levels of all sites under investigation were all within the TWQG range (6 – 12 mg/l) requirements (DWAF, 1996b). This could indicate that the river is currently running under acceptable ranges throughout the year. Changes in this level will be noted during drought seasons and/or heavy rains and flooding seasons.

The COD levels of all sample sites on the uMngeni River ranged between 56 mg/l and 100 mg/l. The increased COD levels are indicative of some sort of pollution occurring in the river system. These pollutions can be attributed to industrial effluents and/or domestic use by squatter developments along the uMngeni River.

The pH levels ranged between 7.1 and 8.12 during this investigation (Table 2.11). The general ranges between 6 and 8 are acceptable by DWAF, 1996b. There seem to be some stability in the pH throughout the sampling sites leaning towards a slight alkaline environment. However, it is noted that the pH in winter months is slightly higher than the summer months except at sites 3 and 4. This could be the result of low flow rate of the river from upper levels of the river. The pH levels of all the sample sites in this investigation on the uMngeni River were within the TWQG (DWAF, 1996b).

The electrical conductivity (EC) ranged from 184 to 301 at the sample sites. The electrical conductivity during the summer months seems to be higher than that of the winter months. This can be attributed to the lower flow rates and increased nutrient loads due to domestic and industrial effluent as well as potential small scale farmers' activities (DWAF, 1996b).

The salt levels, for example chlorides ranging from 28 to 47 and sulphates levels ranging from 2.97 to 5.55, of the uMngeni River are well within the TWQG ranges.

2.3.1.2 Tugela River

Results of current (2011 low-flow and 2012 high-flow surveys) and historical water-quality variables collected from the Thukela River (Figure 1), where available from 2005 to 2012, include water temperature, oxygen, electrical conductivity, pH, nitrate, nitrite, phosphate, ammonia, chlorides, alkalinity, calcium, chemical oxygen demand (COD), sulphates and sodium are presented in Table 2.12 below. Results show that the water quality state of the sites varies considerably with many constituents occurring in elevated levels that may result in negative impacts to the structure and function of the aquatic ecosystems considered. In particular, temperature levels, oxygen levels, nutrient and salt loads have been of concern historically and currently.

Table 2.12: Current water quality data for Tugela River under this investigation

Site	ºC	O_2 (mg/l)	O_2 Satu	EC	pH	NO_2	NO_3	PO_4	N	Cl	TAL	Ca	SO_4	Na	COD
Site1W	16.4	8.77	91.1	297	8.24	0.77	0.09	0.05	0.06	23	83	14.1	13.4	70	42
Site1S	28.9	7.45	87.6	285	8.11	0.79	0.07	0.02	0.04	25	94	10.3	11.2	55	51
Site2W	15.2	9.01	97.4	410	8.01	0.95	0.14	0.01	0.08	19	76	9.66	14.6	49	39
Site2S	27.4	7.14	91.3	402	7.64	1.17	0.17	0.04	0.08	23	90	12.3	13.2	52	67
Site3W	16.8	8.94	95.3	388	8.93	1.86	0.79	0.07	0.06	21	82	11.2	6.92	61	59
Site3S	29.1	7.22	60.4	392	8.21	1.94	0.65	0.05	0.07	31	99	9.90	10.1	59	91
Site4W	17.3	9.10	89.9	265	7.10	1.88	0.72	0.08	0.02	39	59	10.4	12.4	83	97
Site4S	28.9	6.91	87.4	311	8.05	0.85	0.56	0.09	0.05	42	70	12.1	14.7	77	99
Site5W	16.9	9.14	92.1	276	8.22	0.91	0.06	0.11	0.07	30	87	10.2	17.8	64	83
Site5S	29.2	6.32	79.6	299	7.97	1.72	0.09	0.09	0.08	36	99	11.4	16.4	61	101

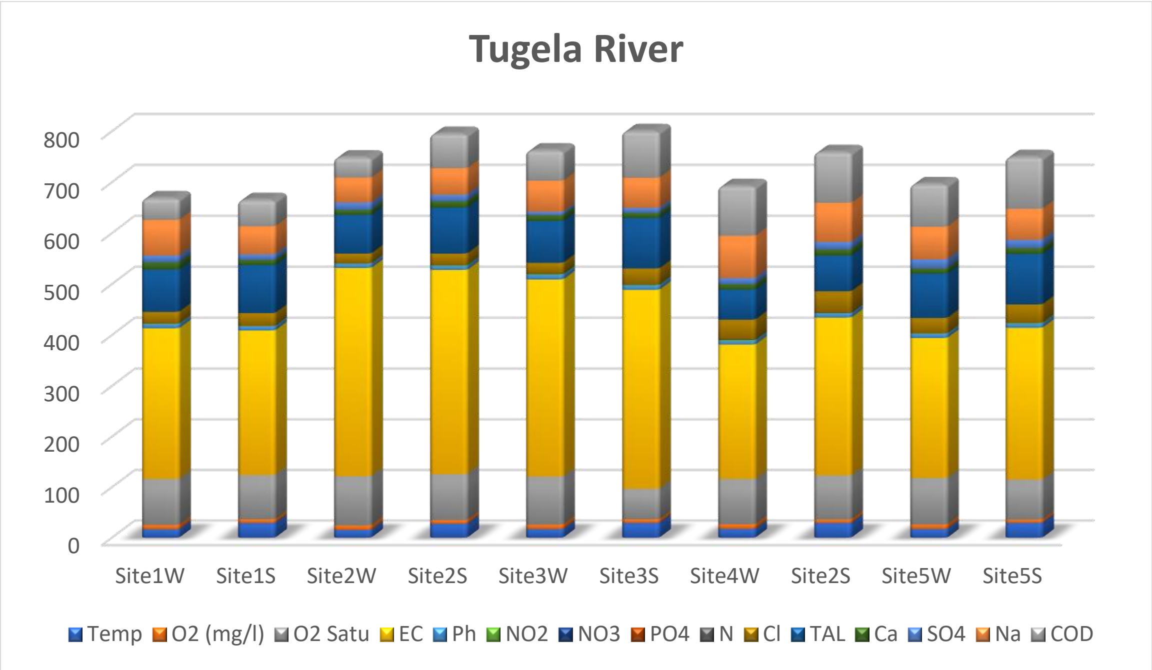

Fig 2.2: Stacked graph of the chemical composition of the Tugela River

Seasonal fluctuations can be clearly observed in the changes in water temperatures during the seasonal sampling times. The temperature ranging between 15.2°C and 29.2°C is well within the TWQG requirements. It is worth noting that the industries located higher up and agricultural activities could have influenced the water temperatures at the points of entry into the river system.

The pH levels at all the sampling sites leaned towards a slight alkaline nature ranging from 7.10 to 8.93. Although industrial activities could cause acidification of the environment, this has not been noted in the river system which clearly showed ranges acceptable as per DWAF (1996b).

The oxygen (mg/l) levels for all the sample sites are well within the range convenient for aquatic ecosystem as per DWAF (1996b). The oxygen level ranged between 6.32 and 9.14. It seemed that during summer the oxygen level was rather lower than that of the winter months. This could be attributed to the increased flow rate of the river due to higher rainfalls. Furthermore, the effluents from the paper mill upstream and the Sugar industrial milling could contribute to the drop in the oxygen levels of the river system thus creating increased chemical oxygen demand. For effective management of the river, measures of reducing excessive effluents from entering the river system should be taken into consideration. Functionality of the river and maintenance of the ecosystem is reliant on the quality of water without pollution from industry ,agriculture and domestic utilization.

The electrical conductivity levels seem to have some stability and ranged between 265 and 410. This is well within the range stipulated by DWAF (1996b) for aquatic ecosystems. This seem to be contradicting previous investigations where there was noticeable fluctuations in the EC of Tugela river due to domestic and industrial effluent discharges and surface runoff from urban and industrial areas that may contribute to increased nutrient levels and salt loads, causing elevated EC levels (DWAF, 1996b; Laxton and Gittins, 2003).

DWAF, (1996b) indicated that surface runoff from catchment areas, effluent containing organic industrial wastes, human and animal excrement and agricultural fertilizers contributed to elevated nutrient loads. The effluent emanating from organic industrial wastes, human and animal excrement, agricultural fertilizers contributes to the increased levels of nutrient loads on the rivers system. The chloride load and the sulphate load seem to be stable at all sampling sites. This can be seen from the levels of nitrates that varied between 0.02 to 0.08 mg/l. The levels for nutrient loads, chloride load as well as sulphate load are well within the range indicated by DWAF, (1996b) for aquatic ecosystems hence showing the stability of the river system.

2.3.1.3 Umvoti River

Table 2.13: Current water quality data for Umvoti River under this investigation

Site	ºC	O_2 (mg/l)	O_2 Satu	EC	pH	NO_2	NO_3	PO_4	N	Cl	TAL	Ca	SO_4	Na	COD
Site1W	15.1	6.76	89.9	201	7.40	1.19	0.17	0.03	0.13	17	51	9.17	10.1	37	29
Site1S	29.3	6.44	85.0	199	8.01	0.99	0.15	0.01	0.11	21	70	8.72	8.28	41	37
Site2W	15.6	8.91	99.5	245	7.91	1.27	1.05	0.04	0.07	13	47	7.45	9.91	22	22
Site2S	28.8	7.33	89.7	213	8.00	1.18	0.97	0.03	0.03	19	65	7.11	10.3	36	31
Site3W	17.1	9.25	100	197	8.13	1.52	1.94	0.06	0.04	25	57	9.18	7.84	27	17
Site3S	29.8	7.28	79.8	184	8.04	1.81	1.55	0.07	0.12	28	81	10.1	9.91	31	28
Site4W	16.7	8.97	97.7	266	7.98	0.97	0.87	0.03	0.01	26	62	6.13	6.67	29	30
Site4S	30.1	6.99	89.4	299	8.15	0.88	0.63	0.01	0.02	35	74	6.24	8.96	42	45
Site5W	16.4	9.11	93.3	254	8.29	1.18	0.09	0.09	0.04	29	59	4.41	9.13	17	23
Site5S	29.5	7.01	83.1	267	7.39	1.69	0.32	0.02	0.03	37	77	7.20	11.2	29	41

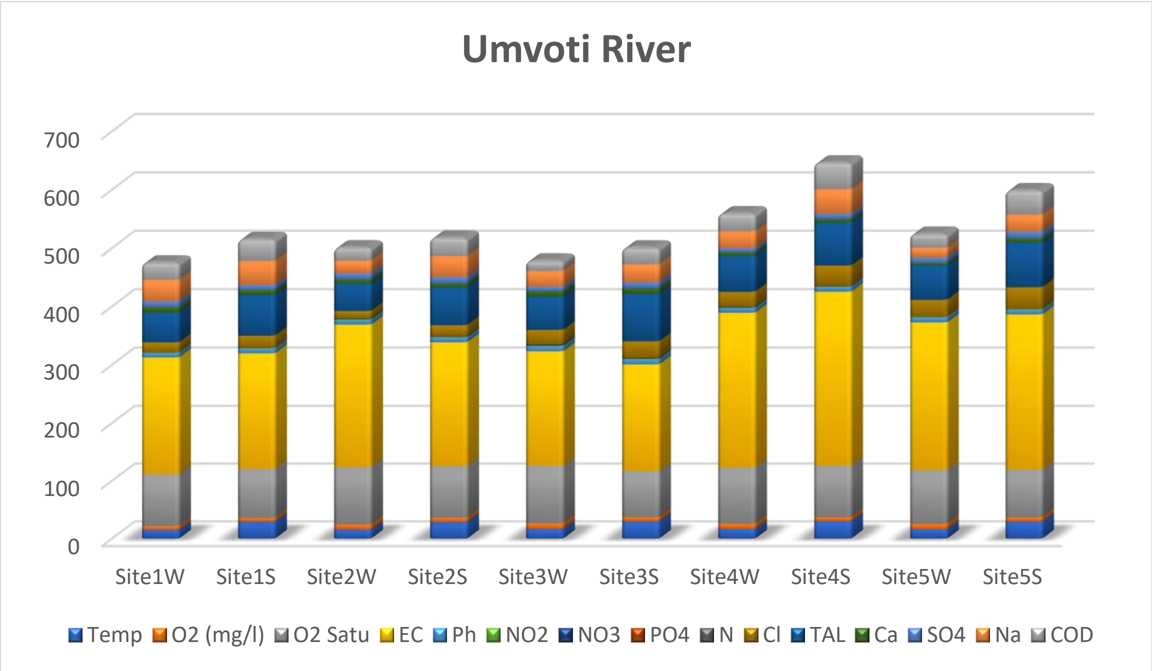

Fig 2.3: Stacked graph of the chemical composition of the Umvoti River

The temperature levels of all the sampled sites ranged between 15.1^{o}C and 30.1^{o}C (Table 2.13). The lower temperatures were recorded for the winter months and the warmer temperatures were for the summer months. A fluctuation in temperature due to seasonal variations reported in previous investigations (Gallagher, 1999) has also been recorded in this study. The higher temperatures noted as per previous investigations occurred at the upper parts of the river. Extremely high temperatures could be detrimental to the functionality of ecosystem of the river. The increases in temperatures could have resulted from extreme climatic changes as well as industrial and agricultural pollutions. The pH of the river was similar to those of the other rivers investigated as it leaned towards a more alkaline direction. The pH ranging between 7.39 and 8.29 were within the range stipulated in DWAF, (1996b). It was observed that informal settlements are the primary users of this river and that they are increasing at a rapid rate. Some subsistence farmers were interviewed to ascertain their knowledge on the river and the management thereof. The waste emanated from these settlements caused the river to have a reduced oxygen level. The oxygen level ranged between 6.44 and 9.25.

2.3.1.4 Umdhloti River

Table 2.14: Current water quality data for Umdhloti River under this investigation

Site	°C	O_2 (mg/l)	O_2 Satu	EC	pH	NO_2	NO_3	PO_4	N	Cl	TAL	Ca	SO_4	Na	COD
Site1W	16.2	7.66	100	310	8.11	2.01	0.92	0.08	0.19	28	81	11.4	17.1	37	59
Site1S	27.8	7.02	97.1	240	7.98	1.34	0.66	0.05	0.13	37	94	9.91	15.4	41	64
Site2W	15.9	8.11	104	276	8.90	1.98	0.73	0.07	0.11	31	66	11.2	17.3	22	37
Site2S	29.0	7.84	91.1	222	8.23	1.51	0.71	0.06	0.09	40	79	8.77	10.7	36	52
Site3W	16.7	8.28	86.3	313	7.91	1.87	0.99	0.09	0.10	29	61	10.9	12.4	27	33
Site3S	28/9	7.91	82.3	299	8.14	1.92	1.10	0.04	0.07	38	82	9.01	10.7	31	49
Site4W	14.9	8.66	98.1	284	8.32	0.91	0.89	0.05	0.08	44	77	9.94	14.2	29	61
Site4S	29.9	7.32	87.4	291	7.78	0.89	0.72	0.02	0.05	53	98	8.32	10.1	42	65
Site5W	16.4	9.25	99.8	288	8.79	1.45	0.44	0.01	0.09	49	62	8.76	15.6	17	39
Site5S	28.8	7.89	90.6	276	8.22	1.93	0.65	0.02	0.07	56	98	7.91	13.9	29	52

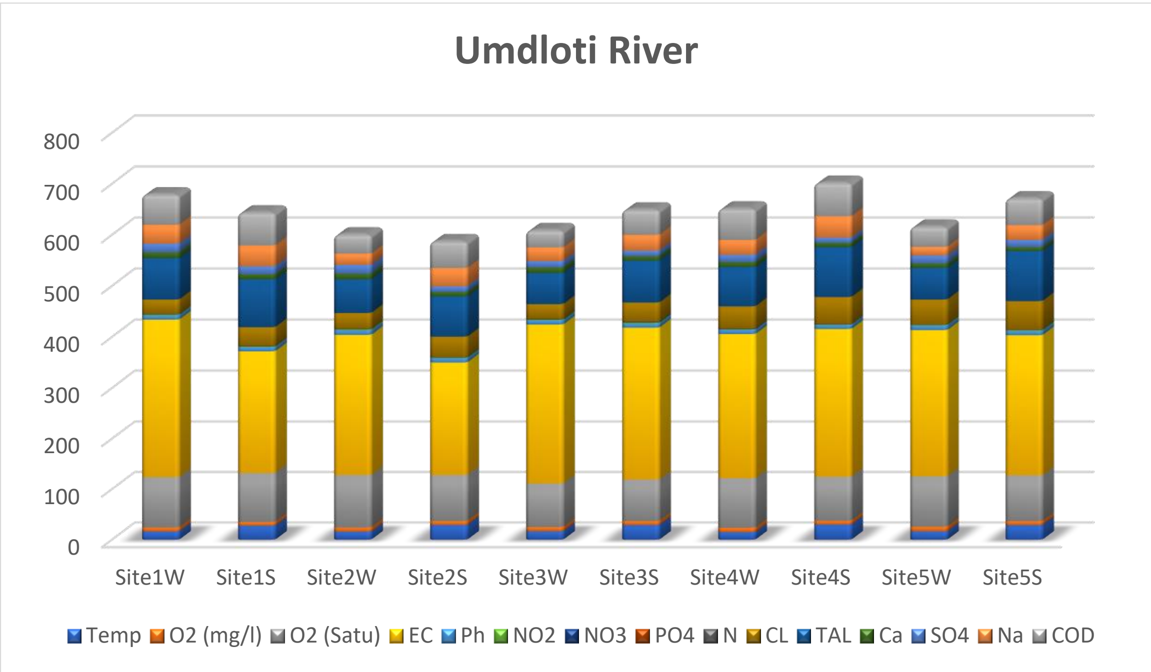

Fig 2.4: Stacked graph of the chemical composition of the Umdloti River

With reference to the temperature levels of all sampled sites, the temperature ranged between 14.9^{o}C and 29.9^{o}C (Table 2.14). This river is heavily sand mined by illegal contractors. This sand mining operation is at the detriment of the indigenous vegetation and a direct impact on the biodiversity of the area which is replicated in the lower reaches of the river system. The lower temperatures were recorded for the winter months and the warmer temperatures were for the summer months and are in agreement with that of previous investigations (Gallagher, 1999). The pH of the river was similar to those of the other rivers investigated as it leaned towards alkalinity. The pH ranging between 7.78 and 8.90 were within the range stipulated in DWAF (1996b). It was known that informal settlements are the primary users of this river and their effects of their activities was further compounded by illegal miners.

2.3.1.5 Umfolozi river:

Table 2.15: Current water quality data for Umfolozi River under this investigation

Site	°C	O_2 (mg/l)	O_2 Satu	EC	pH	NO_2	NO_3	PO_4	N	Cl	TAL	Ca	SO_4	Na	COD
Site1W	14.2	7.11	94.0	297	8.13	0.03	0.28	0.02	0.09	12	77	11.1	37	37	51
Site1S	27.7	7.02	91.1	255	7.89	0.01	0.19	0.01	0.15	19	91	10.8	44	41	33
Site2W	15.1	7.99	100	281	7.71	0.09	0.87	0.05	0.11	14	59	9.75	35	22	42
Site2S	27.9	7.14	94.3	244	7.66	0.05	1.14	0.03	0.17	21	84	9.03	47	36	31
Site3W	16.3	8.33	91.4	307	8.27	0.17	0.99	0.04	0.06	13	59	12.4	41	27	46
Site3S	29.3	7.91	87.4	269	8.11	0.09	1.11	0.03	0.09	19	87	10.9	52	31	32
Site4W	16.1	8.75	99.0	314	7.99	1.12	0.91	0.07	0.04	22	66	8.99	39	29	21
Site4S	29.9	8.01	91.9	292	7.12	0.98	1.01	0.05	0.05	31	91	8.03	57	42	17
Site5W	15.9	8.68	97.3	287	8.33	0.06	0.05	0.03	0.07	19	61	9.25	43	17	42
Site5S	30.5	7.91	87.6	281	7.94	0.04	0.09	0.01	0.09	27	83	8.97	52	29	36

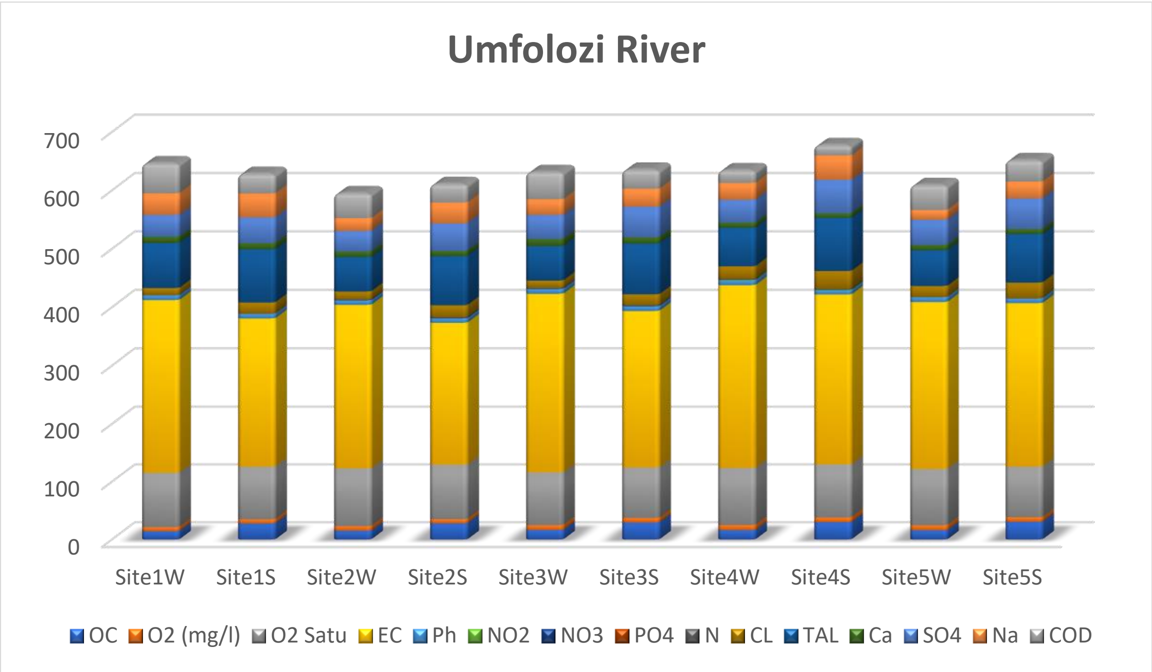

Fig 2.5: Stacked graph of the chemical composition of the Umfolozi River

The Umfolozi River passes through the Hluhluwe-Umfolozi Park on the upper reaches and the Eastern and Western Shore nature reserves at the lower reaches. The temperature levels of all sampled sites ranged between 14.2^{o}C and 30.5^{o}C (Table 2.15). Many informal dwellers were located between the parks that make extensive use of the river for various domestic chores. The organic discharges from these domestic practises can contribute to the oxygen demand of the river system (DWAF, 1996b). The pH of the river was similar to those of other rivers being investigated as it leaned towards a more alkaline direction. The pH ranging between 7.12 and 8.33 was within the range stipulated in DWAF (1996b). The oxygen level ranged between 7.02 and 8.68.

2.4. Sediment

2.4.1. uMngeni River

Table 2.16: Sediment grain-size distribution analyses, moisture content and organic content of uMngeni River. Sample size = 100g

Site	G	VCS	CS	MS	VFS	M	Moisture Content %	Organic content %
Site1W	20.88	6.91	41.38	23.27	6.91	0.64	21.13	1.27
Site1S	21.19	5.53	42.08	25.67	5.23	0.23	20.97	1.31
Site2W	13.99	15.01	42.91	24.32	3.32	0.42	14.77	0.81
Site2S	14.45	15.92	41.15	25.03	2.95	0.44	14.91	0.87
Site3W	9.95	17.23	31.08	39.54	1.85	0.31	10.11	0.81
Site3S	9.15	16.95	31.18	40.31	1.95	0.41	10.78	0.79
Site4W	5.37	8.12	46.94	38.49	0.91	0.14	14.45	0.55
Site4S	4.39	9.01	47.36	38.14	0.89	0.18	12.31	0.59
Site5W	0.97	3.53	51.41	41.98	1.22	0.85	7.17	0.49
Site5S	1.13	3.01	50.94	42.32	1.65	0.91	8.13	0.32

(gravel - G, very coarse sand - VCS, coarse sand - CS, medium sand - MS, very fine sand - VFS and mud - M

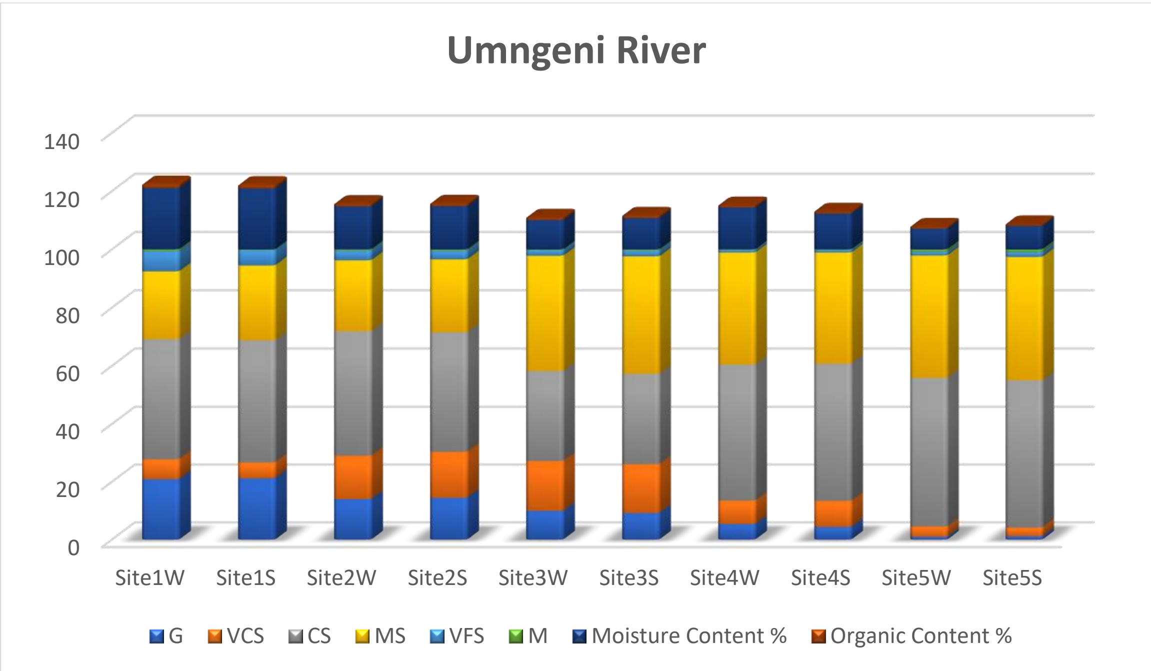

Fig 2.6: Stacked graph of sediment grain-size distribution analyses, moisture content and organic content of uMngeni River.

2.4.2 Tugela

Table 2.17: Sediment grain-size distribution analyses, moisture content and organic content of Tugela River. Sample size = 100g

Site	G	VCS	CS	MS	VFS	M	Moisture Content %	Organic content %
Site1W	17.71	15.71	39.87	21.99	4.36	0.33	22.01	3.22
Site1S	18.04	16.12	39.91	20.57	4.89	0.45	23.43	2.98
Site2W	10.46	20.31	37.53	25.57	5.16	0.95	15.67	1.97
Site2S	9.37	21.02	36.36	26.61	5.98	0.65	13.73	1.88
Site3W	4.41	25.77	29.63	31.19	7.98	0.98	12.44	1.01
Site3S	3.93	27.37	28.93	32.29	6.57	0.88	12.87	0.96
Site4W	1.10	31.08	29.51	31.22	7.01	0.07	10.06	0.91
Site4S	0.93	31.92	30.13	30.79	6.14	0.07	10.17	0.98
Site5W	0.01	32.17	31.08	31.19	5.36	0.16	6.63	0.57
Site5S	0.00	32.93	30.26	31.54	5.01	0.23	7.04	0.44

(gravel - G, very coarse sand - VCS, coarse sand - CS, medium sand - MS, very fine sand - VFS and mud - M

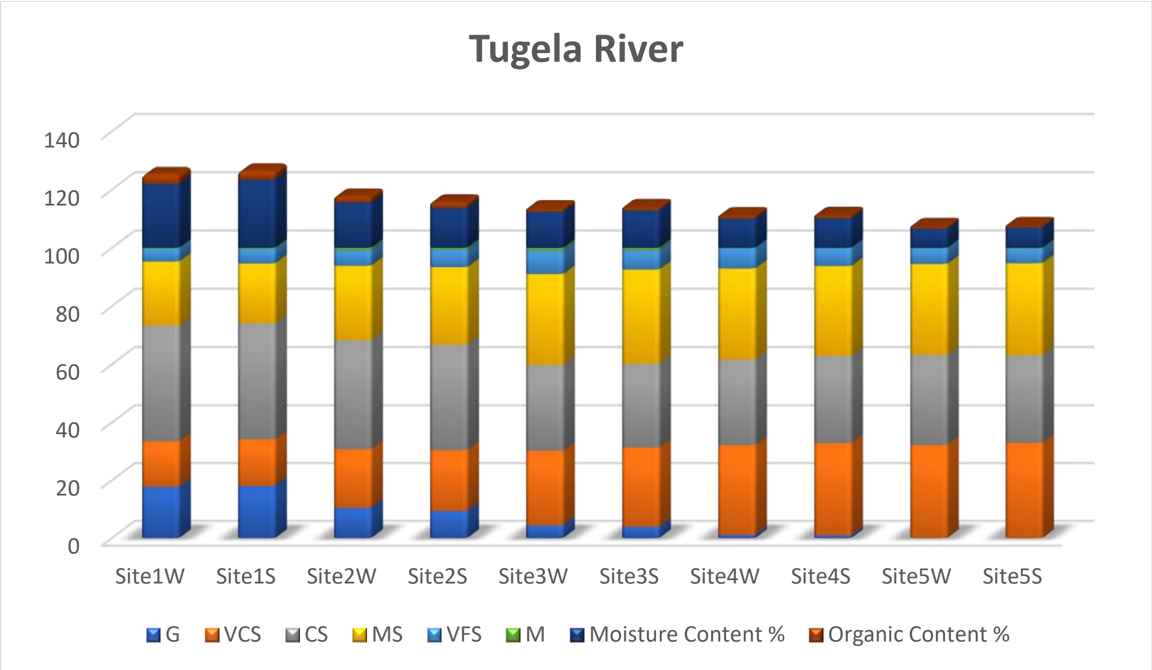

Fig 2.7: Stacked graph of sediment grain-size distribution analyses, moisture content and organic content of Tugela River.

2.4.3 Umvoti

Table 2.18: Sediment grain-size distribution analyses, moisture content and organic content of Umvoti River. Sample size = 100g

Site	G	VCS	CS	MS	VFS	M	Moisture Content %	Organic content %
Site1W	17.23	22.34	31.17	24.79	3.97	0.49	21.91	4.17
Site1S	18.77	21.91	30.97	23.59	4.17	0.56	22.09	3.98
Site2W	13.83	22.13	31.88	24.95	6.44	0.75	14.33	1.76
Site2S	11.81	23.31	31.97	25.97	6.24	0.69	15.01	1.71
Site3W	7.22	28.12	27.75	29.93	5.99	0.96	9.10	0.94
Site3S	8.02	28.98	27.32	29.67	5.23	0.76	8.91	0.95
Site4W	2.97	30.11	29.13	30.87	6.73	0.16	4.47	0.71
Site4S	1.99	29.97	30.98	29.98	6.97	0.09	5.03	0.83
Site5W	0.00	31.42	31.97	31.31	5.11	0.18	5.92	0.62
Site5S	0.00	29.97	32.04	33.21	4.62	0.15	4.11	0.59

(gravel - G, very coarse sand - VCS, coarse sand - CS, medium sand - MS, very fine sand - VFS and mud - M

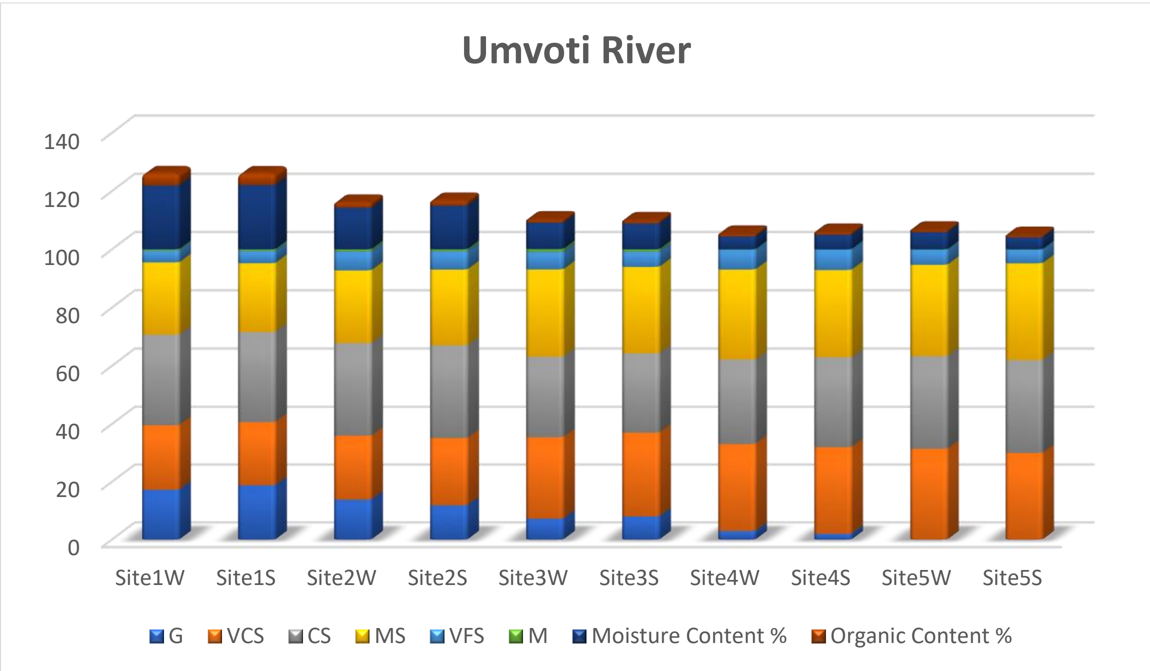

Fig 2.8: Stacked graph of sediment grain-size distribution analyses, moisture content and organic content of Umvoti River.

2.4.4 Umdhloti

Table 2.19: Sediment grain-size distribution analyses, moisture content and organic content of Umhloti River. Sample size = 100g

Site	G	VCS	CS	MS	VFS	M	Moisture Content %	Organic content %
Site1W	20.07	15.92	32.31	25.74	5.07	0.87	20.32	5.17
Site1S	21.33	16.67	31.99	24.29	4.87	0.84	21.09	5.23
Site2W	17.73	20.26	27.66	25.57	7.84	0.93	17.01	1.99
Site2S	18.51	19.98	26.77	26.68	7.14	0.89	17.97	1.97
Site3W	6.83	15.87	33.62	37.19	4.54	1.94	11.99	0.96
Site3S	7.01	14.91	35.47	37.33	4.07	1.17	11.34	0.93
Site4W	2.93	15.11	37.78	39.82	3.67	0.68	8.93	0.77
Site4S	2.04	14.87	38.93	40.97	3.08	0.09	7.74	0.84
Site5W	0	9.91	42.67	45.17	2.13	0.11	6.76	0.69
Site5S	0	8.23	43.36	46.31	1.98	0.09	6.01	0.66

(gravel - G, very coarse sand - VCS, coarse sand - CS, medium sand - MS, very fine sand - VFS and mud - M

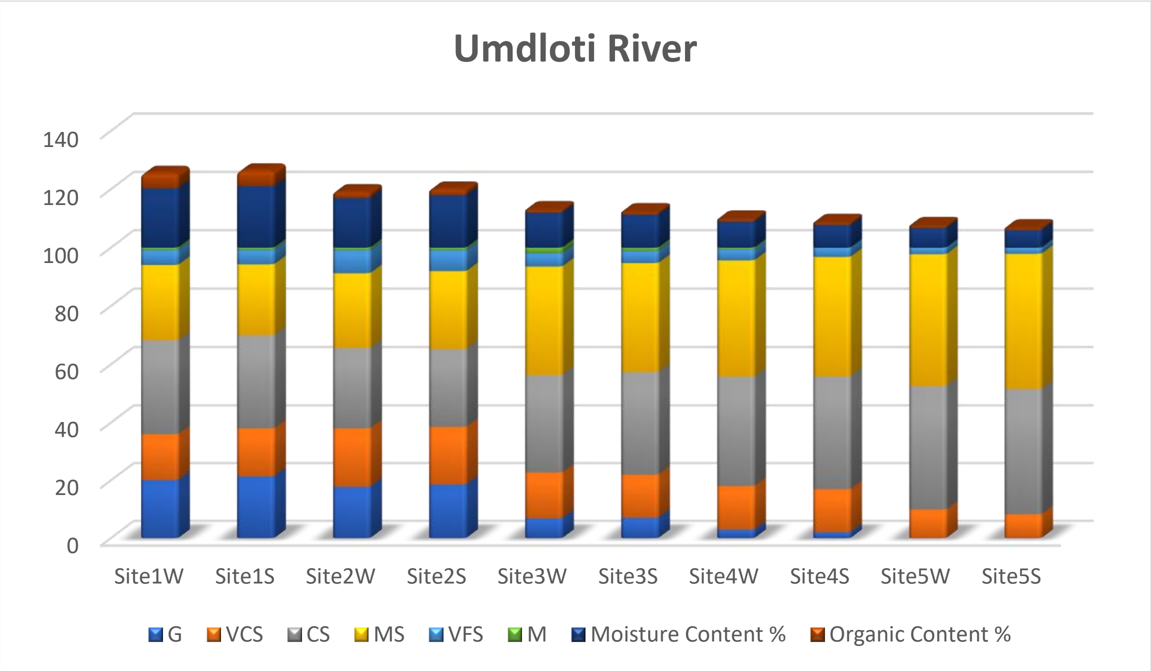

Fig 2.9: Stacked graph of sediment grain-size distribution analyses, moisture content and organic content of Umdloti River.

2.4.5 Umfolozi

Table 2.20: Sediment grain-size distribution analyses, moisture content and organic content of Umfolozi River. Sample size = 100g

Site	G	VCS	CS	MS	VFS	M	Moisture Content %	Organic content %
Site1W	24.13	12.91	28.55	26.91	6.16	1.32	19.32	1.76
Site1S	23.19	13.53	29.27	27.58	5.43	0.97	21.02	2.01
Site2W	19.22	21.03	28.8	21.97	7.93	1.02	16.66	0.97
Site2S	18.99	22.74	29.71	20.63	6.78	1.14	17.01	1.04
Site3W	7.59	10.98	36.93	36.93	6.63	0.93	10.10	0.93
Site3S	7.33	11.19	34.99	38.57	6.91	0.99	11.06	0.91
Site4W	0.00	7.13	42.42	44.89	4.76	0.79	9.91	1.67
Site4S	0.00	6.78	43.51	45.11	4.05	0.53	8.73	1.43
Site5W	0.00	5.97	41.53	49.14	3.17	0.18	6.76	0.97
Site5S	0.00	5.61	42.47	48.98	2.76	0.15	7.31	0.93

(gravel - G, very coarse sand - VCS, coarse sand - CS, medium sand - MS, very fine sand - VFS and mud - M

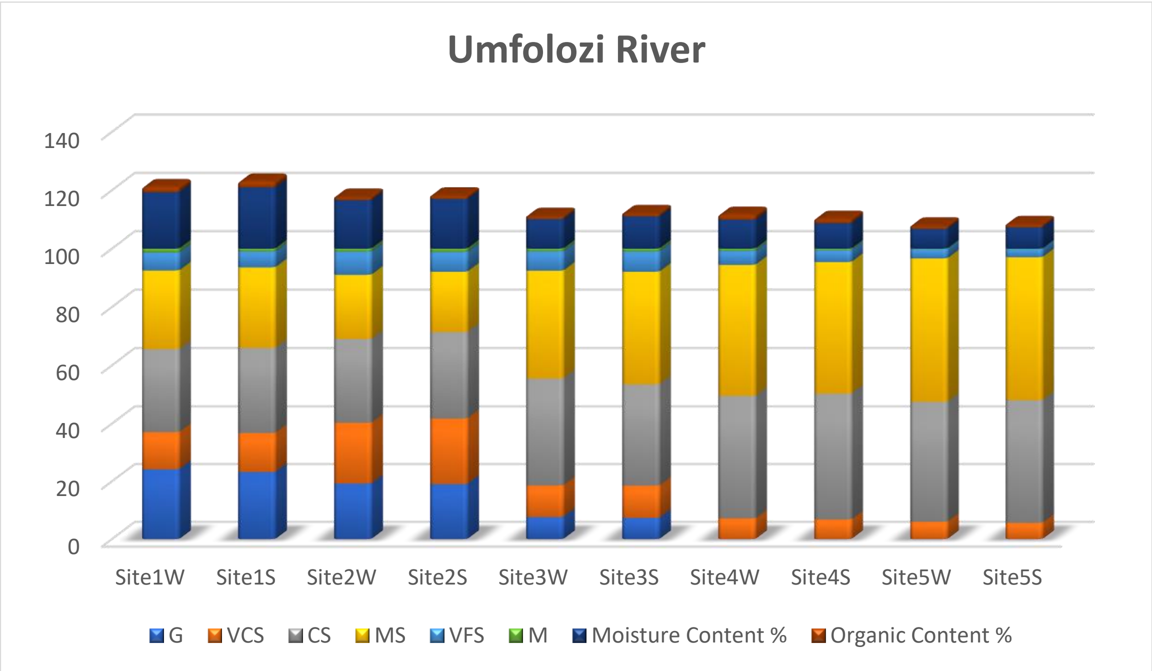

Fig 2.10: Stacked graph of sediment grain-size distribution analyses, moisture content and organic content of Umfolozi River.

Differing sediment type could determine the extent of river pollution and possible erosion emanating from the upper reaches of the river. The sedimentation is also dependent on the type of river and the flow rate of the rivers. Sediments also hold moisture and organic components that settle on the river beds. With higher flow rates, the sedimentation occur at the lower end of the river as the flow will drive all loose particles to the lower reaches. The lower flow rates will allow precipitation and sedimentation at much high points in the river system. According to Carminati (2008), sediment transport increases as the coarseness of the sediment increases. The result of such is a lower biodiversity of aquatic organisms due to the decreases of the available biotopes.

Sites 1 and 2 of all the rivers (Tables 2.16 – 2.20) under this investigation are located at the upper stream as compared to sites 4 and 5. The very coarse content amounting to gravel seem to be at higher levels on the sites 1 and 2 whereas as investigations move closer to the mouth region or lower reaches, the very coarse content was drastically reduced. Predominantly, most of the samples had very coarse sand and medium sand with little fine sand and mud. The moisture content of all sampled areas for all the rivers investigated was higher at the Sites 1, 2 and 3 and much reduced at the Sites 4 and 5. This could be due to the water holding capacity of the fine sand not being able to hold as much water as that of the coarse content. The sediment moisture content for uMngeni, Tugela, Umvoti, Umdhloti and Umfolozi ranges from 21.13% to 8.13%, 22.01% to 7.04%, 21.91% to 4.11%, 20.32% to 6.01% and 19.32% to 7.31% respectively (Tables 2.16 to 2.19). The higher organic content of the upper regions of the river could be due to sewage deposition, industrial wastes, domestic waste deposition, organic debris, sand mining disturbances as well as agricultural runoffs. The organic content of uMngeni, Tugela, Umvoti, Umdhloti and Umfolozi ranged from 1.27% to 0.32%, 3.22% to 0.44%, 4.17% to 0.59%, 5.17% to 0.66% and 1.76% to 0.93% respectively. The two rivers with the highest organic content are Tugela and Umvoti. The agricultural settlement and the industry associated with the Tugela River and Umvoti River were contributing factors to increased siltation in the river system. This is observed by the domination of finer sediments in these rivers (Venter and van Vuren, 1997; Cheesman, 2005; CRUZ, 2000). These higher levels could be due to the direct association of these rivers to sugar cane industry and sewage plants. Similar findings were found in other rivers with such an association (Carminati, 2008; Malherbe, 2006; Stryftombolas, 2008).

2.5. Habitat

2.5.1. Amatikulu River

The availability, diversity and state of the habitat were assessed by means of the Integrated Habitat Assessment System Version 2 (IHAS v 2) which was adopted from McMillan (1998) and the Index of Habitat Integrity (IHI) which was adopted from Kleynhans (1996) and Olliss (2006). The approaches set out by these two indices to assess availability, diversity and state of the habitat were widely implemented throughout the National River Health Programme. These indices were performed by entering various observations on a provided score sheet in the field. The values of the indices were then calculated and a rating system for each index was then used to describe the quality of the habitat of the given site

Table 2.21: Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the Umgeni River

Sites	IHI Score	IHAS Score	IHAS Integrity Class
Site1W	-	55.11	D
Site1S	-	53.45	D
Site2W	47	62.17	C
Site2S	553	61.93	C
Site3W	-	58.36	D
Site3S	-	58.44	D
Site4W	122	39.91	D
Site4S	126	40.33	D
Site5W	-	41.12	D
Site5S	-	41.37	D

Table 2.22: Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the Tugela River

Sites	IHI Score	IHAS Score	IHAS Integrity Class
Site1W	-	58.32	D
Site1S	-	56.77	D
Site2W	121	64.14	C
Site2S	108	63.25	C
Site3W	-	61.23	C
Site3S	-	60.92	C
Site4W	173	38.74	D
Site4S	159	40.44	D
Site5W	-	45.83	D
Site5S	-	41.58	D

Table 2.23: Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the Umvoti River

Sites	IHI Score	IHAS Score	IHAS Integrity Class
Site1W	-	61.71	C
Site1S	-	69.34	C
Site2W	-	60.11	C
Site2S	-	61.23	C
Site3W	37	58.73	D
Site3S	48	59.12	D
Site4W	94	42.52	D
Site4S	106	41.44	D
Site5W	-	60.34	C
Site5S	-	61.48	C

Table 2.24: Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the Umdhloti River

Sites	IHI Score	IHAS Score	IHAS Integrity Class
Site1W	-	43.93	D
Site1S	-	41.22	D
Site2W	145	37.39	D
Site2S	139	39.91	D
Site3W	72	57.77	D
Site3S	64	58.19	D
Site4W	110	45.76	D
Site4S	97	43.96	D
Site5W	-	44.24	D
Site5S	-	41.98	D

Table 2.25: Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the Umfolozi River

Sites	IHI Score	IHAS Score	IHAS Integrity Class
Site1W	-	75.11	C
Site1S	-	73.93	C
Site2W	-	60.61	C
Site2S	-	64.34	C
Site3W	64	49.97	D
Site3S	79	52.65	D
Site4W	128	50.12	D
Site4S	117	49.17	D
Site5W	-	60.97	C
Site5S	1-	63.48	C

Habitat assessments are often undertaken to determine the current biodiversity of the riparian zone and the river itself. If there are changes affecting the riparian zone, there would be a corresponding effect on the river and the functionality of its ecosystem. This ultimately will affect the biodiversity of the river itself. The Integrated Habitat Assessment System (IHAS) represents invertebrate specific habitat state of a river. There are classes assigned to a specific state which depends on the degree of modification either directly or indirectly. The direct modifications are such as sand mining or changes to the area for touristic or monetary gain. The indirect modifications are due to adverse climatic conditions such as heavy rainfalls resulting in excessive water flows and removal of the riparian zone (flood zone). The later is quite reversible as the resilience of the river and its associated banks are quite natural. The former however can never be changed to revert to its original state.

The uMngeni River, Umdhloti River and Umvoti River are modified in the lower reaches for monetary gains. The upper reaches of these rivers are associated with either industrial effluents, sewage seepages or domestic and agricultural depositions. The IHAS assessment classifies most areas of these rivers to be under Class D (Tables 2.21 to 2.25). This is a direct implication that the rivers were generally in a largely modified state. The IHI score indicated both habitat availability and diversity as high or low. A higher score indicated some sort of impairment whereas a low score indicated fewer changes in the habitat which is an indication of near naturalness. The findings in this investigation from all sample sites and all rivers were in line with studies undertaken by other investigators (Malherbe, 2006; Carminati, 2008). Impacts caused by the indigenous folks who set up homes along the river banks of the uMngeni and other rivers contribute to the deterioration of habitat diversity and availability in these Rivers. These impacts include the damage to the indigenous vegetation and disturbance of the riparian zone. The sugarcane agricultural activities, water abstraction and channel modifications of the Tugela and Umvoti river areas are the principal contributors to the deterioration state of the integrity of the habitat.

Comparatively the Umfolozi River seems to be the best in diversity and had the least impact from industry, agriculture and human domestication uses. The water quality was found to be in a fairly good, slightly modified state, the majority of water quality parameters considered was within the target values set by the TWQG. Water quality parameters considered on the lower. The Tugela River, uMngeni River, Umdloti River and the Umvoti River were seen to be in a modified state producing negative impacts on the functionality of the rivers.

2.6 Conclusion:

All the five rivers investigated were partially or heavily deteriorated due to the presence of heavy metals in the river system as pollutants. Measures have to be taken to facilitate and control sources of these pollutions. However, the drive is to ascertain the actual causative contributor and implement stricter rules and harsher fines to ensure the longevity of the river system and at the same time promote biodiversity conservation. Control of invasive vegetation need be considered a priority.

CHAPTER 3

Ecological integrity using SASS 5 for the uMngeni, Tugela, Umvoti, Umdloti and Umfolozi Rivers in KwaZulu-Natal

3.1. Introduction

Rivers can be assessed by various indicators such as the vegetation types, the fish populations, the types of macro-invertebrates for their ecological integrity and the state of health (Barbour *et al*., 1996; Thirion, 2007). Any change in the structures of the aquatic macro-invertebrate community will provide information on the effects or direct stress of the water body. These stressors are the water quality, pollution, hydrological and geomorphological processes and habitat alterations (Dallas, 2000; Álvarez-Cabria *et al*., 2010; Holt and Miller, 2011). Due to their wide distribution, macro-invertebrates have been known to be ideal ecological indicator. They are easily sampled, sensitive to even the slightest changes in ecosystem states, have a large-scale applicability and can be used across regions (Álvarez-Cabria *et al*., 2010). In South Africa, several methodologies incorporate aquatic macro-invertebrates as biological indicators. The South African Scoring System, Version 5 (SASS 5) (Dickens and Graham, 2002), the Macro-Invertebrate Response Assessment Index (MIRIA) (Thirion, 2007) and the use of multivariate statistical analysis are currently used throughout South Africa. The ecosystem variables that are used in these assessments include water quality and habitat variables which are referred to as ecological driver components which are the main components of the South African Scoring System (SASS 5) used as a biological index of water quality (Dickens and Graham, 2002).

This South African Scoring System is now the benchmarked guidelines where all rivers can be assessed on its ecological integrity and community structures. The technique also provide valuable information regarding the current state of ecological integrity of the aquatic macro-invertebrate communities (Dickens and Graham, 2002; Thirion, 2007). The credibility of the South African Scoring System is not questionable as it has been revised and improved upon since it was developed in 1994 and is now in its 5th revision, hence the acronym SASS 5 (Dickens and Graham, 2002). Different families show different tolerance to pollutions and range from highly tolerant families (e.g. Muscidae and Psychodidae) to less tolerant families (e.g. Oligoneuridae).

The Macro-Invertebrate Response Assessment Index (MIRAI) method used the information generated by SASS to evaluate the water-quality and -quantity impacts and at the same time assess the habitat suitability for aquatic macro-invertebrates (Thirion, 2007). This method delivers to the end user the habitat-based cause-and-effect which then can be used to interpret the deviation of the aquatic macro-invertebrate assemblage attributes from a pre-established reference condition (Thirion, 2007). The most often used approach nationally is the SASS 5 method (Thirion, 2007). Van den Brink *et al.* (2003) indicated that several multivariate statistical techniques have also been used to evaluate the structure of aquatic macro-invertebrate assemblages and their response to different altered ecosystem driver components. To determine community structure, Multivariate statistical analyses techniques is the most often used. This method also derives the patterns in various ecosystems (Ter Braak, 1994; Van den Brink *et al.,* 2003; O‟Brien *et al.,* 2009). Statistical analysis for this study was undertaken by a qualified statistician

3.2. Materials and methods

3.2.1. South African Scoring System (SASS) (refer to Annexure for example of spreadsheet for SASS sampling)

Samples of different micro-invertebrates were taken from the five sites of the uMngeni River, Tugela River, Umvoti River, Umdloti River and Umfolozi River during summer and winter respectively to ascertain differences due to seasonal variations. The surveys were undertaken using the SASS 5 method which involves the collection of macro-invertebrates according to the standardised SASS protocol at three different habitat types or biotopes according to Dickens and Graham (2002). The three different biotopes include stones (in current, out of current and bedrock) sampled for 2 min, marginal vegetation (total length of 2 m), and gravel, sand and mud (GSM) sampled from 30 to 60 s. Sampling was done with a standard SASS net (1 mm mesh and dimensions of 30 x 30 x 30 cm) and analysed separately according to the standardised protocol in order to be able to consider habitat availability. Specimen samples were preserved in 10% neutral buffered formaldehyde and stained with phloxine dye and transported to the laboratory for identification with the aid of a dissection microscope and guided by the macro-invertebrate guide (Kleynhans, 1999; Dickens and Graham, 2002).

SASS results are expressed both as index score (SASS score) and the average score per recorded taxon (ASPT) and the results (SASS scores and ASPT values) were then analysed using the SASS data interpretation guidelines (Dallas, 2005; Dallas, 2007). SASS assessment were done the same way as investigations carried out in previous studies on other rivers (CRUZ, 2000; O'Brien *et al*.,2005; Malherbe, 2006; Cloete *et al.*, 2008; Ferreira *et al.*, 2008; Malherbe *et al.*, 2008; Stryftombolas, 2008; O'Brien *et al.*, 2009; O'Brien, 2010).

Table 3.1: Habitat integrity classes for IHAS and description of each class, adopted from Kleynhans (1999)

Ecological Category	Description of category	Acceptable/ Unacceptable
A	Unmodified, natural state, macro-invertebrate communities compare with reference assemblages	Acceptable
B	Largely natural with few modifications. A small change in natural habitats and macro-invertebrate communities may have taken place, but the ecosystem functions are essentially unchanged	Acceptable
C	Moderately modified. A loss of natural habitats and moderate change in macro-invertebrate community structure. Ecosystem functioning still predominately unchanged.	Acceptable
D	Largely modified. A loss of natural habitat and large change in macro-invertebrate community structures. Ecosystem functions are impaired.	Unacceptable
E	Seriously modified. Extensive loss in natural habitats and change to macro-invertebrate community structures. Ecosystem function disruptions are extensive.	Unacceptable
F	Critical or extensively modified. Modifications have reached a critical level resulting in almost complete loss of natural habitat and macro-invertebrate community structures. In worse cases basic ecosystem functions have been completely removed and changes are irreversible.	Unacceptable

3.3. Results and Discussion

3.3.1. South African Scoring System (SASS 5)

Each river was sampled in both seasons making a total of ten assessments. From the assessments, the number of taxa as well as the diversity was noted. The ASPT value was generated by dividing the SASS score by the number of taxa for each sampled site. Tables 3.2 indicated the SASS scores, Number of taxa and the ASPT for each of the rivers under this investigation.

Table 3.2: SASS 5 Summary for uMngeni River

Scores	Site1W	Site1S	Site2W	Site2S	Site3W	Site3S	Site4W	Site4S	Site5W	Site5S
NO. OF TAXA	23	25	19	20	21	21	25	24	28	28
SASS SCORE	143	147	139	139	117	118	150	149	150	150
ASPT	6.22	5.88	7.32	6.95	5.57	5.62	6.00	6.21	5.36	5.36

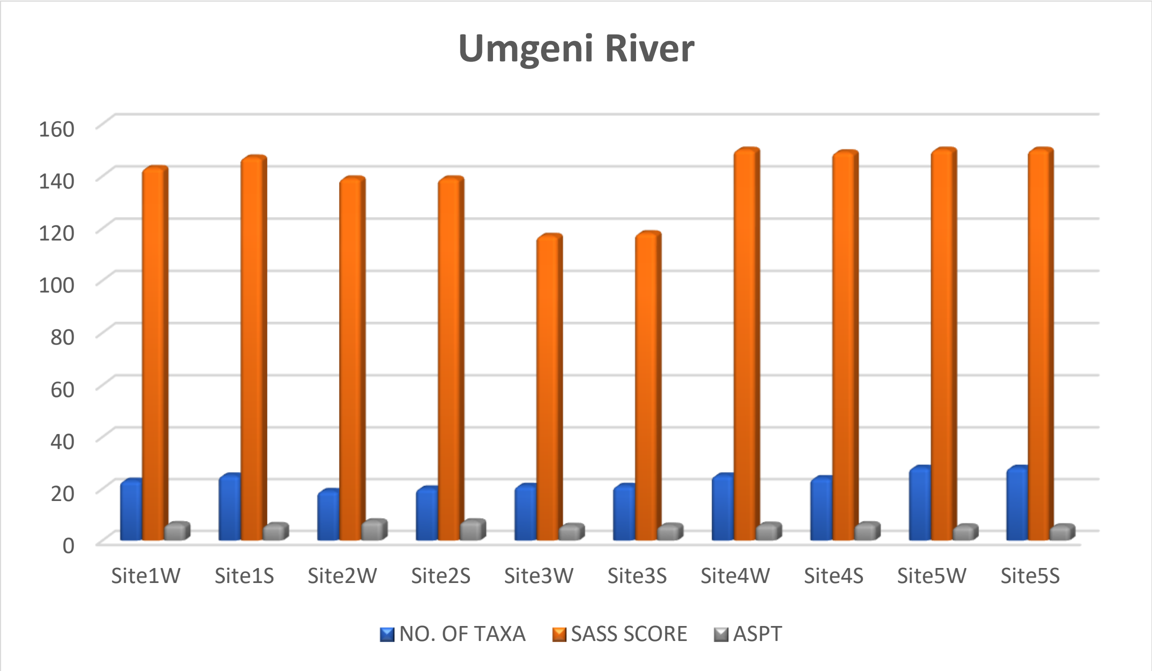

Fig 3.1: SASS5 Score for Umgeni River

Table 3.3: SASS 5 Summary for Tugela River

Scores	Site1W	Site1S	Site2W	Site2S	Site3W	Site3S	Site4W	Site4S	Site5W	Site5S
NO. OF TAXA	33	32	23	24	27	26	17	19	27	27
SASS SCORE	210	210	144	146	148	148	110	115	149	150
ASPT	6.36	6.56	6.26	6.08	5.48	5.69	6.47	6.05	5.52	5.56

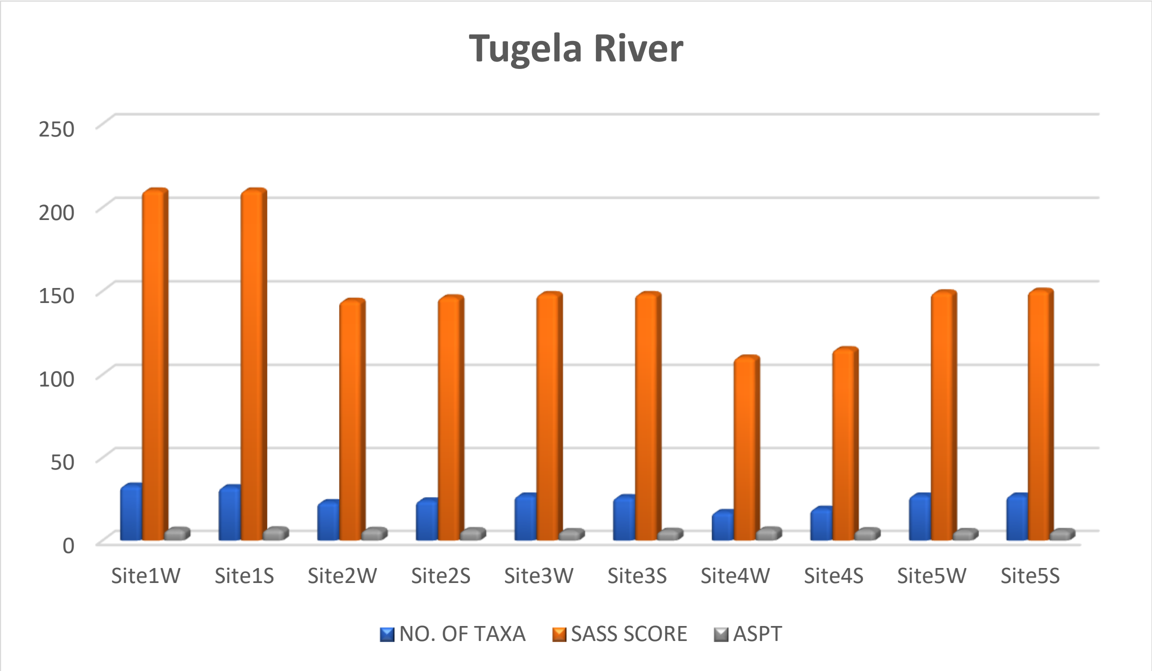

Fig 3.2: SASS5 Score for Tugela River

Table 3.4: SASS 5 Summary for Umvoti River

Scores	Site1W	Site1S	Site2W	Site2S	Site3W	Site3S	Site4W	Site4S	Site5W	Site5S
NO. OF TAXA	25	23	21	23	21	23	20	23	19	21
SASS SCORE	177	176	141	142	120	124	119	122	104	106
ASPT	7.08	7.65	6.71	6.17	5.71	5.39	5.95	5.30	5.47	5.05

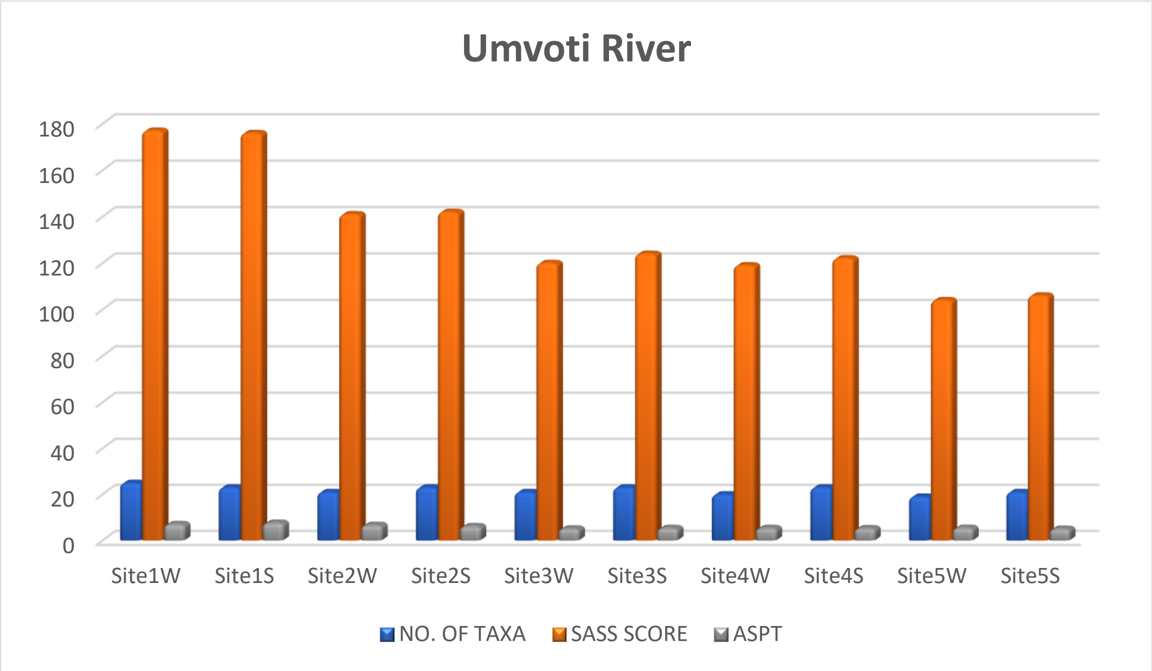

Fig 3.3: SASS5 Score for Umvoti River

Table 3.5: SASS 5 Summary for Umdloti River

Scores	Site1W	Site1S	Site2W	Site2S	Site3W	Site3S	Site4W	Site4S	Site5W	Site5S
NO. OF TAXA	16	18	20	21	19	18	22	23	23	22
SASS SCORE	79	82	110	109	110	106	132	137	139	142
ASPT	4.94	4.56	5.50	5.19	5.79	5.89	6.00	5.96	6.04	6.45

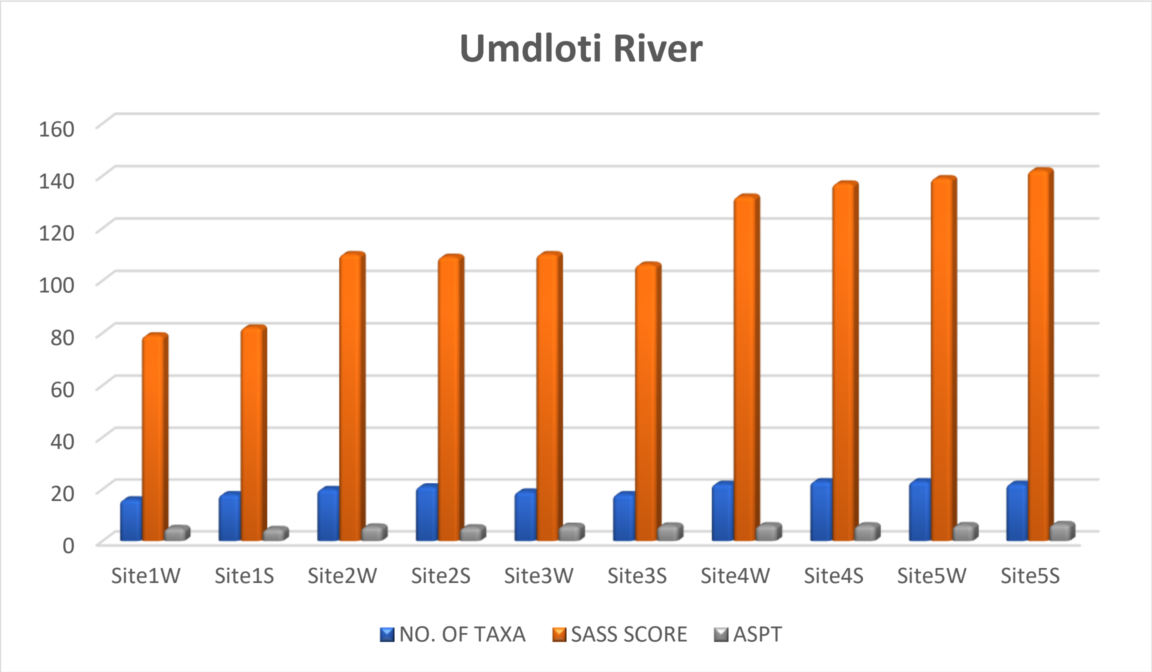

Fig 3.4: SASS5 Score for Umdloti River

Table 3.6: SASS 5 Summary for Umfolozi River

Scores	Site1W	Site1S	Site2W	Site2S	Site3W	Site3S	Site4W	Site4S	Site5W	Site5S
NO. OF TAXA	27	27	23	22	29	29	23	23	29	29
SASS SCORE	147	148	140	139	186	188	149	149	175	177
ASPT	5.44	5.48	6.09	6.32	6.41	6.48	6.48	6.48	6.03	6.10

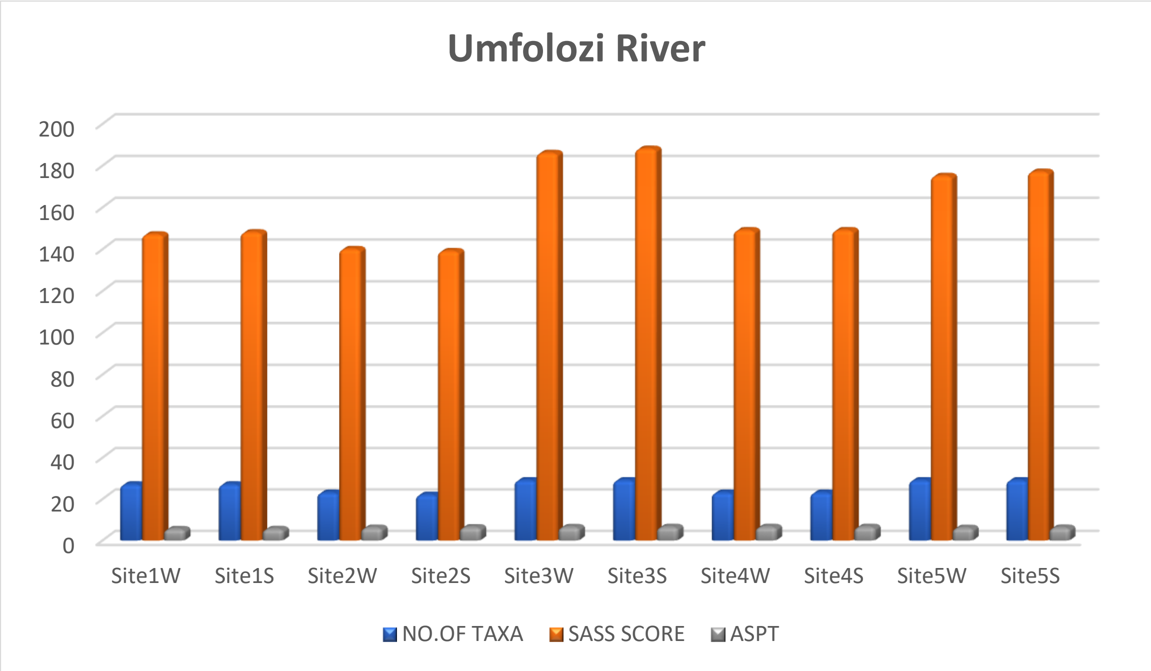

Fig 3.5: SASS5 Score for Umfolozi River

The SASS 5 assessment for all the five rivers under this investigation seems to have some sort of consistency in the number of taxa which ranged between 16 and 33. The Tugela River had the most number of taxa in Site 1W and differed slightly from Site 1S. The lowest number of taxa was noted at the Umdhloti River ranging between 16 and 23 with the lowest ASPT value of 4.56 and 4.94. Across all rivers, the ASPT values for the winter assessments seem to be much better than the summer values.

Previous investigation on the Umvoti River showed that SASS scores were better during high flow periods as compared to low flow periods (Carminati, 2008). This could be due to the low flow periods having little effect on the organisms associated with rock and stones that form homes for these organisms. However, the organisms are easily washed down the river due to the high pressure of the flow during the high flow periods. The summer months are predominated by random rainfall. Hence, the summer months had a much lower SASS score as compared to the winter months. Furthermore, sedimentation as well as abstractions contributed to the water flows of the rivers. The rivers which are more affected by sedimentation and abstractions due to the industrial influence are the Umvoti River, Umgeni River and Tugela River. These sedimentation and abstraction resulted in flow modification had a rippled effect on the lower reaches of the river. The Umvoti River is associated with effluents from the paper mill (SAPPI) and the sewage plants near the Stanger region. These effluents affected the biodiversity of the river itself due to the increased chemical and waste pollution that these plants would contribute and ultimately affect the SASS score of the river (Stryftombolas, 2008; O'Brien, 2010a). The Umdhloti River is mainly affected by the extensive sand mining operation currently taking place just after the Verulam area. The sand mining is impacting on the biodiversity of the riparian vegetation and that of the river itself.

The most taxa collected for uMngeni River was 28 which were at the site nearest the lower reaches of the river. For Tugela River, Umvoti River, Umdhloti River and Umfolozi River, the number of taxa collected were 33, 25, 23 and 29 respectively. The least taxa collected for uMngeni River, Tugela River, Umvoti River, Umdhloti River and Umfolozi River were 19, 17, 19, 16 and 22 respectively (Tables 3.2 to 3.6).

3.4. Conclusion

The SASS scores for all the rivers are relatively low but constant with the lowest being that of Umdloti River. Deterioration of water quality due to industrial and domestic influence could be the driving factor for the low scores. The poor water quality due to the increased pollution creates a poor habitat for organisms and the macro-invertebrate community structures that occupied these rivers. As conservationist's, there is a need to implement stricter measures to reduce the effects of pollution resulting from effluents in industry and effluents from sewage plants as well as prevent illegal sand mining to prevent further destruction of the rivers under this investigation.

CHAPTER 4

Assessment of fish populations and bacterial levels of the uMngeni, uThukela, Umvoti, Umdloti and Umfolozi Rivers, KwaZulu-Natal

4.1 Introduction

4.1.1 Fish populations

Fresh water bodies tend to end in estuaries at the lower reaches of the system. The fresh water bodies such as rivers and estuaries form homes and nesting areas for most fish species. Any pollution in the river or fresh water system will affect fish populations of a river system. In many investigations, fish assemblages are commonly used as key indicators to describe the ecological state of aquatic ecosystems (Maceda-Veiga and De Sostoa, 2011). The determination of fish assemblages is a good ecological indicator due to their longevity and the ability to move through various habitats (DWAF, 1999; Todd and Roux, 2000; Whitfield and Elliott, 2002; Van der Oost *et al.,* 2003; Harrison and Whitfield, 2004; Maceda-Veiga and De Sostoa, 2011; Cabral *et al.,* 2012; Gamito *et al.,* 2012). There are limitations to this as the fish population can be affected in different ways from each river due to variation and diversity in environmental conditions (Whitfield and Elliott, 2002; Harrison and Whitfield, 2004; Cabral *et al.,* 2012; Gamito *et al.,* 2012).

Estuaries are highly known to provide nursery areas for marine fish (Harrison *et al.,* 2000; Turpie., 2002). The diversity of fish species is linked directly to the characteristic of an estuary (Harrison *et al.,* 2000). Estuaries experience a fluctuation in salt concentrations due to seawater and fresh water constantly influencing the salinity, temperature, dissolved oxygen sedimentation and turbidity. This places a considerable physiological demand on the fishes that occupy these systems (Harrison and Whitfield, 2006; Elliott *et al*., 2007).

This chapter centres around the fish populations during winter and summer seasons in uMngeni River, Tugela River, Umvoti River, Umdloti River and Umfolozi River.

Table 4.1: The FRAI ecological integrity state categories as well as a description of each category, adopted from Kleynhans (1999)

Ecological Category	Description of category	Acceptable/ Unacceptable	FRAI Score
A	Unmodified, natural state, Fish communities compare with reference assemblages	Acceptable	90 – 100
B	Largely natural with few modifications. A small change in natural habitats and Fish communities may have taken place, but the ecosystem functions are essentially unchanged	Acceptable	80 – 89
C	Moderately modified. A loss of natural habitats and moderate change in Fish community structure. Ecosystem functioning still predominately unchanged.	Acceptable	60 – 79
D	Largely modified. A loss of natural habitat and large change in Fish community structures. Ecosystem functions are impaired.	Unacceptable	40 – 59
E	Seriously modified. Extensive loss in natural habitats and change to Fish community structures. Ecosystem function disruptions are extensive.	Unacceptable	20 – 39
F	Critical or extensively modified. Modifications have reached a critical level resulting in almost complete loss of natural habitat and Fish community structures. In worse cases basic ecosystem functions have been completely removed and changes are irreversible.	Unacceptable	0 – 19

Table 4.2: Fish species expected in type-F subtropical estuaries (adapted from Harrison *et al*., 2000)

Acanthopagrus berda	*Megalops cyprinoids*
Agrosomus japonicas	*Mugil cephalus*
Ambassis gymnocephalus	*Myxus capensis*
Ambassis natalensis	*Oligolepis acutipentis*
Ambassis productus	*Oligolepsis keiensis*
Caranx ignobilis	*Oreochromis mossambicus*
Caranx sexfasiatus	*Pomadasys commersonnii*
Elops machnata	*Rhabdosargus holubi*
Gilchristella aestuaria	*Rhabdosargus sarba*
Glossogobius callidus	*Scomberoides lysan*
Hilsa kelee	*Solea bleekeri*
Leiognathus equula	*Terapon jarbua*
Liza alata	*Thryssa vitrirostris*
Liza dumerilii	*Valamugil buchnani*
Liza macrolepis	*Valamugil cunnesius*
Liza tricuspidens	*Valamugil robustus*

The uMngeni River is blessed with abundance of fish species. It has been reported that the uMngeni River boasts about 48 species of freshwater fish. Thirty six of the fishes are indigenous while 12 fishes are alien. Furthermore, 57 fish species are found in the uMngeni Estuary in Durban (DWAF, 2017).

Table 4.3: Some of the freshwater fish species found in Umgeni River (DWAF, 2017)

Common Name	**Species Names (# means alien)**
River beam	*Acanthopa grusberda*
Longspine glassy	*Ambassis productus*
Natal mountain catfish	*Amphilius natalensis*
African mottle eel	*Anguilla bengalensis labiate*
Madagascar mottle eel	*Anguilla marmorata*
Longfin eel Anguilla	*Anguilla mossambica*
Natal topminnow	*Aplochilichthys myaposae*
Freshwater goby	*Awaousa eneofuscus*
Chubbyhead bard	*Barbus anoplus*
Redtail bard	*Barbus gurneyi*
Straightfin bard	*Barbus paladinosus*
Bowstripe bard	*Barbus viviporus*
Duckbill sleeps	*Butis butis*
Goldfish	*Carassius auratus #*
Sharptooth catfish	*Clarias gariepinus*
Grass carp	*Clenopharyngodon idella #*
Carp	*Cyprius carpio #*
Dusky sleeper	*Eleo trisfusca*
Black throat goby	*Favonigo biusmelano brachus*
Tropical sand-goby	*Favonigo biusreichei*
Mosquito fish	*Gambusia affinis#*

4.1.2: Microbiological analysis

The major problem facing water bodies is the issue of pathogen transport. The process of identifying microorganisms that can potentially spread through the water supply is quite a daunting task (Salgot *et al.,* 2001). In most river systems, the bacterial indicators such as coliforms are used to assess water quality. However, the presence of other microorganisms such as protozoa and viruses is often disregarded during these monitoring activities (Straub and Chandler, 2003).

The selection of quality microbial indicator is essential. There are specific characteristics that could be used to select an appropriate indicator, and they include

- An indicator that is universally present in the faeces of humans and warm-blooded animals in large numbers
- It must readily be detected by simple methods
- Can grow in natural waters, the general environment or water distribution systems
- Be persistent in water and the degree to which it is removed by water treatment is comparable to those of waterborne pathogens (WHO;1990; NHMRC-ARMCANZ, 2003).

The presence of different bacterial species was done in most rivers that are associated with industries, agricultural process, sewage treatment plants as well as domestic wastes. The summer/winter test for bacteriophages in the uMngeni River had ealier revealed a vast amount of contamination in the river system (Lin *et al.,* 2012).

Table 4.4: Presence – Absence spot test (based on plaque formation) for the determination of somatic bacteriophages and F-RNA coliphages in the uMngeni River water samples using host specific *E. coli* ATCC 13786 and *S. typhimurium* WG49 respectively (Adopted from Li, *et al*., 2012).

Sample	Presence – Absence Spot Test		
	Location	**Somatic Coliphage**	**F-RNA Coliphage**
Autumn	U1	+++	++
	U2	++	+
	U3	+++	+++
	U4	+	+
	U5	+	-
Winter	U1	++	+
	U2	+++	+
	U3	++	+
	U4	+	+
	U5	+	-
Spring	U1	+ + +	+ + +
	U2	+ + +	+ +
	U3	+ + +	+ + +
	U4	+ +	+
	U5	+	+
Summer	U1	+ + +	+ + +
	U2	+ + +	+ +
	U3	+ +	+
	U4	+ + +	+
	U5	+ +	+

Plaque Formation (cell lysis): +: Weak Plaque; ++: Average Plaque; +++: Strong Plaque; - : No Plaques

This chapter does not involve an extensive investigation into the fish populations, but addresses the type of fish currently existing in each of the rivers under investigation. The determination of the Fish Response Assessment index (FRAI) has been extensively investigated and it would be a futile exercise to undertake such an investigation again. However, the FRAI in South Africa is commonly used to determine the state of ecological integrity of fish assemblages in aquatic ecosystems and is implemented by the National River Health Programme (RHP) (Kleynhans, 2007). The Chapter also addresses the microbial content of each river under investigation.

4.2: Materials and Methods

4.2.1. Field sampling Fish

Sampling was done at the sites as it was done in previous chapters. Both summer and winter samples were taken to ascertain changes in the population type during seasonal fluctuations. The survey was undertaken as per previous investigations, with modifications on fresh water ecosystems (Meador *et al.,* 1993; Barbour *et al.*, 1999). Samplings were done on three different occasions with the best sample size as noted on the table of results. In summary, the netting techniques included the use of a seine net (12 mm mesh, 5 m long). This net was hauled through all shallow (less than 1 m depth) habitats onto sand banks at all sites dominated by sandy bottoms. Additionally, a medium sized seine net (22 mm mesh, 30 m long, fitted with a bag) was used through deep (greater than 1 m) open water habitats at all of the sandy bottomed sites. The habitats that were sampled include slow (<0.3 m/s) deep (> 1m), slow shallow (< 1m), fast (>0.3 m/s) deep and shallow as well as areas with marginal and overhanging vegetation. The physical condition of the area was also noted. Changes in the environmental conditions are related to fish stress and formed the basis of ecological response interpretation

4.2.2: Microbial sampling:

Soil samples from each river were collected from the sampling areas in clean 100 ml bottles. The bottles were washed first with the water from the sample area before collections were done. Three samples were taken from each area. The samples were then transported to the laboratory for further analysis.

4.2.2.1 Nutrient Media Preparation

Fifty eight grams of MacConkey Agar Purple was weighed and dispense in an Erlenmeyer flask containing 1L of distilled water. The agar was mixed well and allowed to stand for 10 min. The agar was autoclaved for 20 min at 121^{o}C and at 2 atmospheric pressures before being poured into sterile petri dishes and allowed to set before use.

4.2.2.2: Methodology – Soil analysis

Ninety nine millilitres of distilled water was poured into an Erlenmeyer Flask. Soil samples weighing 1g was diluted in each flask for each river to make a final solution of 100 g/ml. The flasks were left to agitate on an orbital shaker for 15 min at 100 rpm. A 10-fold serial dilution was prepared by pipetting 1ml of the original sample and diluting it serially on culture tubes containing 9 ml of distilled water - $1x10^{1}$,$1x10^{2}$,$1x10^{3}$,$1x10^{4}$,$1x10^{5}$ and $1x10^{6}$. The $1x10^{6}$ dilution was taken and passed through a sterile filter paper embedded on a funnel assembly of a vacuum pump. The samples were allowed to run completely through the filter. The filter paper was removed from the vacuum pump with sterile forceps and aseptically placed on the surface of a Salmonella Shigella Agar. Plates were sealed with parafilm and incubated upside down for 48 h at 37^{o}C. Colonies forming unit/100 ml after incubation were then counted.

4.3: RESULTS:

4.3.1: Fish Species found in rivers under investigation:

Table 4.5: Fish Species in Rivers under investigation (Table of list of fish species adopted from DWAF 2017)

Common Name	Species Names (# means alien)	uMngeni		Tugela		Umvoti		Umdlhoti		Umfolozi	
		S	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**
River beam	*Acanthopa grusberda*	4	1	7	5	14	5	8	3	12	6
Slender glassy	*Ambassis natalensis*	-	-	-	-	3	-	-	-	1	-
River goby	*Glossogobius callidus* (Smith, 1937)	2	2	6	4	-	-	-	-	-	-
Longfin eel	*Anguilla mossambica*	-	-	5	1	1	1	-	-	4	2
Freshwater goby	*Awaousa eneofuscus*	-	-	2	2	-	-	-	-	1	-
Threespot Barb	*Barbus trimaculus* (Peters, 1852)	6	2	10	4	19	14	2	-	14	5
Mozambique tilapia	*Oreochromis mossambicus* (Peters, 1852)	13	7	22	14	17	5	10	9	31	17
Fresh water Mullet	*Myxus capensis* (Valenciennes, 1836)	10	4	16	9	7	2	2	-	6	1
Common mullet	*Mullet fry*	7	2	47	19	2	2	4	-	8	7

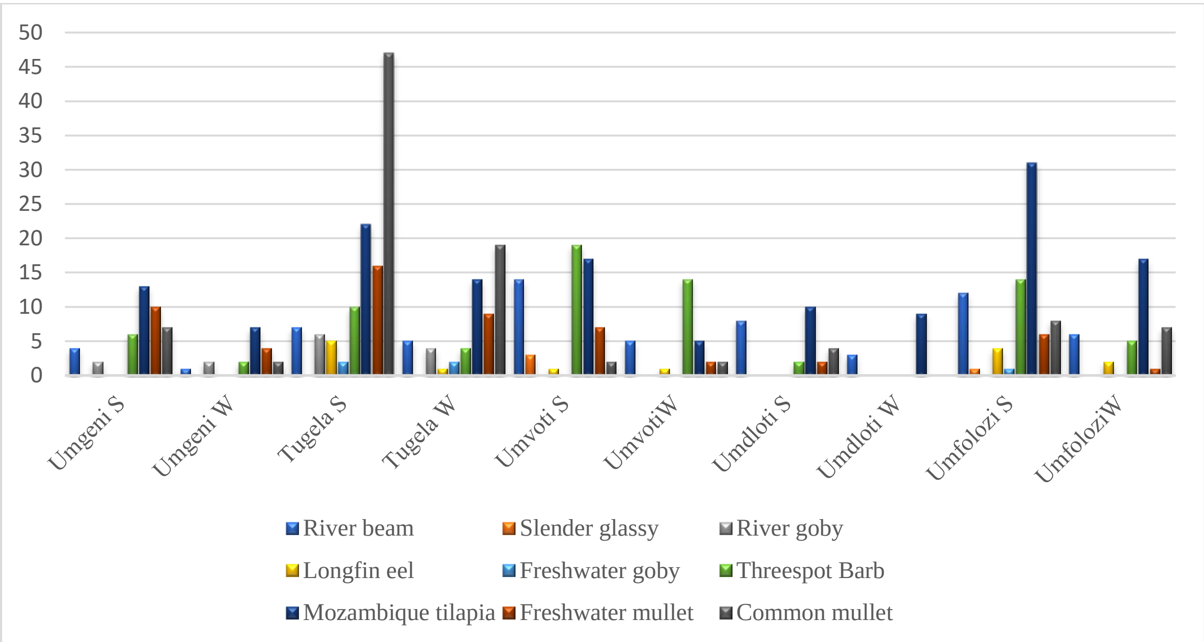

Fig 4.1: Graph showing the distribution of fish species across the rivers under investigation

4.3.2: Soil sample analysis:

Table 4.6: Shows colony forming units for different soil samples from uMngeni, Tugela, Umfolozi, Umdloti and Umvoti Rivers,

	uMngeni	Tugela	Umfolozi	Umdloti	Umvoti
Umgeni ($1x10^6$)	cfu/100ml	cfu/100ml	cfu/100ml	cfu/100ml	cfu/100ml
Sample 1 Salmonella Shigella (SS) Agar	4	19	6	9	11
Sample 2 MacConkey Agar Purple	10	11	8	23	8
Sample 3 Nutrient Agar	89	48	26	67	78

An investigation on the fish community structure of various estuaries indicated that each estuary has a specific community of fish species (Harrison *et al*., 2000). Research by Allanson and Baird (1999) indicated that information on the larval biology and ecology of most fish taxa is generally lacking.

According to Turpie (2002), the lower reaches of a river system, especially the estuaries, are not only well known in terms of their biodiversity due to their migratory ability. Hence the river system, especially the estuarine areas, is used as a transit to the sea and at most a nursery for many fish species. Harrison *et al*. (2000) also indicated that the fish species occurring in lower reaches of the rivers, especially estuaries, have an ability to adapt to variations in salinity, temperatures and pH. The environmental variation is due to the mixing of marine water with fresh water during the tidal changes which brings about abrupt changes in salinity, temperature, dissolved oxygen and turbidity which place considerable physiological demands on the fishes that occupy these systems (Harrison and Whitfield, 2006a). Estuaries provide nursery areas for marine fish species. Approximately 40% of the fish species occurring in estuaries are marine species that occupy the estuary for nursery sites or intermittent foraging areas during high tides. It is known that the estuaries and/or lower reaches of the river system has a fluctuation in salinity levels due to the changes in the ocean tides. Species occurring in these areas need to become tolerant to this salinity changes (Harrison *et al*., 2000).

There is a major need for responses by river management authorities to report on the status of rivers according to their environmental changes. This would bring about awareness and the need to improve ecosystems resource and feed into the policies of the management plans of river ecosystems (Whitfield and Elliot 2002, Harrison and Whitfield 2004).

The investigation of the five rivers showed some common species that occurs in all the rivers in KwaZulu Natal. These species could be used as indicator species on river health. A decline in any of these species should be an alarm as it would indicate some sort of disturbance to the river system. In total 9 fish species were netted in all the five rivers under investigation. The most predominant species were *Acanthopa grusberda* (River bream), *Oreochromis mossambicus* (Mozambique tilapia) and *Myxus capensis* (Fresh water mullet). Most of the species were found to be under overhanging vegetation as well as within the reeds that occupy the river system in certain areas.

All soil samples tested positive for *Salmonella* and *Shigella*. They were lactose-nonfermenters because they were mostly transparent and colourless. Some colonies produced black-centered colonies which means they can produce H_2S.

MacConkey Agar showed both lactose-fermenting and lactose-non-fermenting organisms. The colonies formed were a combination of brown to red in colour whilst some were colourless. Possible colonies detected were Gram-negative. *Escherichia coli* was characterised by red colonies and *Salmonella enteric* appeared as colourless colonies.

Nutrient Agar produced colourless colonies from all the soil samples assayed and it was the only media that produced colonies that were consistently over 20 cfu/100ml from all soil samples. Nutrient agar is a non-selective and non-deferential agar allowing growth of all organisms present on the samples.

The microbial analysis indicated pollution due to the various activities occur at the upper reaches of the river system. Industrial, agricultural and domestic uses are the key contributors to this pollution. It is suggested that control measures should be put in place to eliminate this problem.

4.5: Conclusion:

The diversity of fish species recorded in all rivers under investigation revealed similarities of species. However, previous investigations revealed a much more diverse population in most rivers. There seem to be a decline in the composition of the fish species available in these rivers. Furthermore it has been noted that the number of individual fish species sampled is lower during the winter months rather than the summer months. This is of concern as it does indicate that these rivers are undergoing some sort of disturbance or due to a drop in the temperature of the environment during winter. Furthermore, there seem to be commonalities in the microbial colonies in all rivers under investigation. These microorganisms could be contributing factors to the detriment to the rivers system and could contribute to the reduction in the diversity of the fish species of the rivers.

CHAPTER 5

Evaluation of heavy metal contamination in riparian vegetation along all rivers under this investigation

5.1: Introduction

One major concern that affects plant species in rivers systems which replicates in the destruction of biodiversity is the accumulation of heavy metals in the environment. This poses a threat to both human health and the natural environment. The metals are not biodegradable and hence accumulate in the environment. Contaminants such as mercury, arsenic, nickel, lead, cadmium and chromium enter the environment through industrial waste, extensive sand mining, indiscriminate agricultural practices and landfill run off. Contamination can then be extended into agricultural crops which then impacts onto food security.

Vegetables are known to be rich sources of vitamins, minerals and fibers which also have beneficial anti-oxidative and medicinal properties. Heavy metal contamination of agricultural crops is one of the important aspects of food quality assurance (Khan *et al*., 2008). International and national regulations on food quality have lowered the maximum permissible levels of toxic metals in food items due to an increased awareness of the risk these metals pose to food chain contamination (Radwan and Salama, 2006).

Rapid and unorganized urban and industrial developments have contributed to the elevated levels of heavy metals in the urban environment of developing countries such as China (Wong *et al*., 2003) and India (Tripathi *et al*., 1997; Khillare *et al*., 2004; Mashall, 2004; Sharma *et al*., 2008a and b). Heavy metals are non-biodegradable and persistence environmental contaminants which may be deposited on the surfaces and then absorbed into the tissues of plants. Plants take up heavy metals by absorbing them from polluted environments such as contaminated soils and water (Sharma *et al*., 2008).

All rivers under this current investigation are associated with either one or more of the following Industry, agriculture and domestic utilization. Many of the indigent people also practice small scale subsistence farming along some of these rivers. Hence, the vegetable crops can easily absorb the heavy metals which can be transported to the leaves where it can either cause diseases to the plants or become passed on to the consumers of these vegetables. The feasibility of conventional technologies involving the removal of potential harmful elements from polluted soils by transportation to laboratories, washing with chemicals to remove these heavy metals, and finally replacing the soil at its original location or disposing it of hazardous waste is questioned (Mulligan *et al*. 2001). This decontamination strategy is an *ex situ* approach and can be very expensive and damaging to the soil structure and ecology (Russello and Amato 2007). Immobilization of potential harmful elements through the addition of lime and calcium carbonate ($CaCO_3$) have been suggested as remediation techniques (Ruttens *et al*. 2010). Heavy metals which are known to enter the soils as potential harmful elements (PHEs), are released into the environment by various anthropogenic activities such as industrial manufacturing processes, domestic refuse and waste materials. If these concentrations are too high in soils, then the potential of destruction of natural terrestrial ecosystems is highly possible (Wei *et al*., 2007). Soil management can also change its physical, chemical and biological characteristics and as a result, different responses by biological activities to harmful elements toxicity can be observed. According to Wani *et al*. (2007), all heavy metals have strong toxic activities on organisms that promote plant growth. Erosion of exposed soils due to sand mining or other removal activities can result in substantial sediment loading in surface waters and drainage ways. Spills and leaks of hazardous materials and the deposition of contaminated windblown dust can lead to soil contamination (Davydova, 2005). Emission of heavy metals from the industries and vehicles may be deposited in the vegetable surfaces during their production, transport and marketing. Jassir *et al*. (2005) have reported elevated levels of heavy metals in vegetables sold in the markets at Riyadh city in Saudi Arabia due to the atmospheric deposition. Recently, Sharma *et al*. (2008) have reported that atmospheric deposition can significantly elevates the levels of contamination of heavy metals in the vegetables commonly sold in the markets of Varanasi, India.

The ecosystem associated with many of the rivers in South Africa has an impressive amount of resources which replicates into one of the best biodiversity environment. However, there are recent trends of this biodiversity being threatened. Contamination of natural environment with heavy metals is one of the main global ecological problems.

This study was undertaken to evaluate the accumulation of heavy metals in the riparian vegetation along the rivers under this investigation.

5.2: Methodology

5.2.1: Study area

Samples were collected from the farmer designated points of each river near points where either industrial or agricultural or domestic activities were noticed.

5.2.2 Sample collection and preparation

Total of five soil vegetation samples were taken at the river edge followed by those at 1 m, 2 m, 3 m and 4 m away from the river at each point. The samples were washed with de-ionized water to remove any possible contaminants such as pesticides, fertilizers, dust or mud from the outer surface such that it does not influence the results. Samples were cut into small pieces using a sterile stainless steel knife and separated into shoots and roots then weighed before drying at 65^{o}C to a constant mass for about three weeks. Once dried, samples were weighed and grounded into powder using ceramic mortar and pestle to reduce the dried material size for digestion and analysis purposes.

Soil samples were collected from the rhizosphere of the vegetable samples. Soil samples from the same site were mixed to form a composite sample. These samples were air dried to remove moisture after which they were sieved through a 2 mm sieve.

5.2.3 Digestion and analysis

Samples were taken to the chemistry laboratory, Mangosuthu University of Technology for digestion. The finely ground material were weighed on the scale and divided into samples of 0.5g and digested with 6ml nitric acid; 2ml hydrochloric acid and 3ml hydrofluoric acid which were placed in dry, clean digestion tubes. Dried samples were digested in a microwave digester system Solv, multivalve PRO at 70°C, 1300W for 30 mins. After removal from the digester, the tubes were allowed to cool. Thereafter samples were taken to detect elements using (ICP-MS) Spectrometer.

5.3: RESULTS

The following tables show the results of the sampled collected. Elements were detected using Inductively Couple Plasma Spectrometer (ICP-MS), bio-accumulation factor (BCF) and translocation factor (TF)

Table 5.1: Amount of heavy metals detected in soil, roots and shoots in Umgeni River sampled (mgkg^{-1})

Umgeni River						
Metals	**Symbols**	**Soil**	**Roots**	**Shoots**	**Bcf**	**TF**
Silver	Ag	430230,50	15384,03	113910,91	0,26	7,40
Aluminium	Al	756332591,80	46331965,85	130416546,10	0,17	2,81
Arsenic	As	-33043276,48	-495154,97	-1452208,77	0,04	2,93
Barium	Ba	71396136,45	21492389,40	30154499,48	0,42	1,40
Beryllium	Be	154407,29	-26952,57	-17974,10	-0,12	0,67
Bismuth	Bi	387755,77	21460,47	299801,68	0,77	13,97
Cadmium	Cd	44810,30	655,50	2995,66	0,07	4,57
Cobalt	Co	4871080,90	86268,97	323040,06	0,07	3,74
Chromium	Cr	69904359,76	1147580,49	4194174,32	0,06	3,65
Caesium	Cs	846590,55	22845,33	40438,24	0,05	1,77
Copper	Cu	9181994,15	802002,75	14007018,25	**1,53**	17,47
Iron	Fe	-58902647157,00	-830671743,20	-5697730487,00	0,10	6,86
Gallium	Ga	3174770,49	301375,67	588567,36	0,19	1,95
Indium	In	74012,04	5621,85	51472,37	0,70	9,16
Potassium	K	339673748,60	-	-	-	-
Nickel	Ni	11751984,02	192400,84	798579,48	0,07	4,15
Magnesium	Mg	23837165,48	725116948,10	-	-	-
Sodium	Na	-	-	-	-	-
Lithium	Li	1339318,35	14540,81	109616,49	0,08	7,54
Lead	Pb	17603530,25	503844,81	890832,01	0,05	1,77
Zinc	Zn	9422293,77	2058378,07	5568049,94	0,59	2,71

Table 5.2: Amount of heavy metals detected in soil, roots and shoots in Tugela River ($mgkg^{-1}$)

Tugela River						
Metals	**Symbols**	**Soil**	**Roots**	**Shoots**	**Bcf**	**TF**
Silver	Ag	2338010,267	7732,677624	45173,80531	0,02	5,84
Aluminum	Al	855215316,9	10944270,72	11073251,53	0,01	1,01
Arsenic	As	-45738341,16	-529293,003	-1044420,35	0,02	1,97
Barium	Ba	188148321,3	3600815,056	1965080,58	0,01	0,55
Beryllium	Be	209879,8598	-30269,52245	-28516,04867	-0,14	0,94
Bismuth	Bi	191572,7111	9491,696354	53736,40166	0,28	5,66
Cadmium	Cd	50926,16169	-1820,118106	-2198,125827	-0,04	1,21
Cobalt	Co	8929795,271	48307,45084	73776,35852	0,01	1,53
Chromium	Cr	128177078,2	308926,9203	1176367,657	0,01	3,81
Cesium	Cs	1185492,113	11051,17052	17469,87189	0,01	1,58
Copper	Cu	11875756,48	685747,0527	162965,3565	0,01	0,24
Iron	Fe	-82286891491	-138803073	-599496185	0,01	4,32
Gallium	Ga	7630352,463	56776,73543	62074,58907	0,01	1,09
Indium	In	55002,6901	1960,81964	19809,08439	0,36	10,10
Potassium	K	381035379,1	1261174767	-	-	-
Nickel	Ni	13160978,59	75719,58741	128871,9194	0,01	1,70
Magnesium	Mg	13203076,29	607696218,6	156947753,2	**11,89**	0,26
Sodium	Na	-	-	-	-	-
Lithium	Li	4607807,419	-3429,820239	19907,67227	0,00	-5,80
Lead	Pb	31697693,7	82046,74262	233939,5782	0,01	2,85
Zinc	Zn	9500516,573	1579881,123	642461,8787	0,07	0,41

Table 5.3: Amount of heavy metals detected in soil, roots and shoots in Umvoti River ($mgkg^{-1}$)

			Umvoti River			
Metals	**Symbols**	**Soil**	**Roots**	**Shoots**	**Bcf**	**TF**
Silver	Ag	241937,5203	-7118,726808	95954,4953	0,40	-13,48
Aluminum	Al	559595153,8	110149647,4	28491572,31	0,05	0,26
Arsenic	As	-24929741,03	22930,51019	-950979,4637	0,04	-41,47
Barium	Ba	139814765,8	14710100,28	4674300,988	0,03	0,32
Beryllium	Be	192648,5826	-22817,58875	-27018,53721	-0,14	1,18
Bismuth	Bi	108009,9886	9845,907919	26721,10167	0,25	2,71
Cadmium	Cd	36301,85139	3131,127546	-2217,790969	-0,06	-0,71
Cobalt	Co	7594382,658	204977,2167	145324,4491	0,02	0,71
Chromium	Cr	60770105,09	1138754,046	1083610,321	0,02	0,95
Cesium	Cs	889359,8387	53823,15488	14244,35621	0,02	0,26
Copper	Cu	6086073,69	4067376,962	238713,7238	0,04	0,06
Iron	Fe	-45168641077	-1603779386	-1107745599	0,02	0,69
Gallium	Ga	6357377,485	241422,0445	113496,8105	0,02	0,47
Indium	In	28494,9262	2944,346341	4493,737718	0,16	1,53
Potassium	K	265630296	-	1053793374	**3,97**	-
Nickel	Ni	10784662,99	275802,3016	154886,39	0,01	0,56
Magnesium	Mg	18648131,68	517263768,9	168308161,2	**9,03**	0,33
Sodium	Na	-	-	-	-	-
Lithium	Li	606071,3085	80465,05429	13710,51464	0,02	0,17
Lead	Pb	22051407,64	1220278,063	620832,233	0,03	0,51
Zinc	Zn	6311449,906	1437451,934	310569,512	0,05	0,22

Table 5.4: Amount of heavy metals detected in soil, roots and shoots in Umdloti River (mgkg^{-1})

		Umdloti River				
Metals	**Symbols**	**Soil**	**Roots**	**Shoots**	**Bcf**	**TF**
Silver	Ag	241937,5203	-7118,726808	95954,4953	0,40	-13,48
Aluminum	Al	559595153,8	110149647,4	28491572,31	0,05	0,26
Arsenic	As	-24929741,03	22930,51019	-950979,4637	0,04	-41,47
Barium	Ba	139814765,8	14710100,28	4674300,988	0,03	0,32
Beryllium	Be	192648,5826	-22817,58875	-27018,53721	-0,14	1,18
Bismuth	Bi	108009,9886	9845,907919	26721,10167	0,25	2,71
Cadmium	Cd	36301,85139	3131,127546	-2217,790969	-0,06	-0,71
Cobalt	Co	7594382,658	204977,2167	145324,4491	0,02	0,71
Chromium	Cr	60770105,09	1138754,046	1083610,321	0,02	0,95
Cesium	Cs	889359,8387	53823,15488	14244,35621	0,02	0,26
Copper	Cu	6086073,69	4067376,962	238713,7238	0,04	0,06
Iron	Fe	-45168641077	-1603779386	-1107745599	0,02	0,69
Gallium	Ga	6357377,485	241422,0445	113496,8105	0,02	0,47
Indium	In	28494,9262	2944,346341	4493,737718	0,16	1,53
Potassium	K	265630296	-	1053793374	3,97	-
Nickel	Ni	10784662,99	275802,3016	154886,39	0,01	0,56
Magnesium	Mg	18648131,68	517263768,9	168308161,2	9,03	0,33
Sodium	Na	-	-	-	-	-
Lithium	Li	606071,3085	80465,05429	13710,51464	0,02	0,17
Lead	Pb	22051407,64	1220278,063	620832,233	0,03	0,51
Zinc	Zn	6311449,906	1437451,934	310569,512	0,05	0,22

Table 5.5: Amount of heavy metals detected in soil, roots and shoots in Umfolozi River ($mgkg^{-1}$)

Umfolozi River						
Metals	**Symbols**	**Soil**	**Roots**	**Shoots**	**Bcf**	**TF**
Silver	Ag	2358410,1	7332,99624	45173,80531	0,02	5,74
Aluminum	Al	855215316,9	10944270,72	11073251,53	0,01	0.99
Arsenic	As	-45738341,2	-529293,003	-1044420,35	0,02	1,57
Barium	Ba	188148321,3	3600815,056	1965080,58	0,01	0,55
Beryllium	Be	209879,87	-30269,52245	-28516,04867	-0,09	0,54
Bismuth	Bi	191572,71	9491,696354	53736,40166	0,28	4,36
Cadmium	Cd	50926,17	-1820,118106	-2198,125827	-0,05	1,32
Cobalt	Co	8849795,31	48307,45084	73776,35852	0,01	1,66
Chromium	Cr	12765343,2	387692,9203	1274387,657	0,01	3,32
Cesium	Cs	1185492,113	11051,17052	17469,87189	0,01	1,17
Copper	Cu	11875756,48	685747,0527	162965,3565	0,01	0,30
Iron	Fe	-82286891491	-138803073	-599496185	0,01	4,01
Gallium	Ga	7630352,463	56776,73543	62074,58907	0,01	0.99
Indium	In	55002,6901	1960,81964	19809,08439	0,36	11.01
Potassium	K	381035379,1	1261174767	-	-	-
Nickel	Ni	13160978,59	75719,58741	128871,9194	0,01	1,70
Magnesium	Mg	13203076,29	607696218,6	156947753,2	9.97	0,21
Sodium	Na	-	-	-	-	-
Lithium	Li	4607807,419	-3429,820239	19007,67427	0,01	-4,90
Lead	Pb	31697693,7	82046,74262	233939,5782	0,01	2,85
Zinc	Zn	9500516,573	1579881,123	642461,8787	0,07	0,41

5.4: Discussion

Samples from all the rivers displayed some sort of contaminations of the river system. The soils as well as the vegetation samples displayed presence of heavy metal in both the root and the shoots (Tables 5.1 to 5.5). The Potentially Harmful Elements (PHEs) seem to be taken up by all the vegetation samples. The process of absorption from the roots transported to the leaves and other parts of the plant body included storage of these heavy metals as the plant is unable to excrete them once absorbed. The potential of these metals being taken up by agricultural vegetation is highly possible. In some samples, Silver (Ag) was totally transported to the leaves where it is stored.

In Umdloti River and the Umfolozi River, there seemed to be presence of Ag as well. This could be due to illegal sand mining activities that disturbed the metal concentration of the surroundings which is then passed on to the river system. As for the Umvoti River, the Ag taken up is lower than that detected in the Umdloti and the Umfolozi River. There is a large amount of all the PHEs absorbed by the samples of uMngeni and Tugela Rivers. All samples from all rivers had a relatively high level of heavy metal concentration as compared to the permissible limits in the vegetable crops where all the four (Ag, Zn, Pb and Cu) metals (IS/WHO/FAO, 2001).

The bio-concentration (BCF) is important during scientific analysis of harm that heavy metals as it may be detrimental to humans and the environment (Alexander, 1999; Arnot and Gobas, 2006). The BCF for the qualified elements was calculated with the following formula:

$BCF = C_{shoot}/C_{soil}$. Where C_{shoot} = the concentration of the element in the shoot, and C_{soil} = concentration of the element in the soil sample (Wilson and Pyatt 2007; Zhuang *et al*. 2007)

Ma *et al.* (2001) and Cluis (2004) stated that BCF values classify plants species as hyper accumulators and accumulators (BCF > 1 $mg.kg^{-1}$), or excluders (BCF < 1 $mg.kg^{-1}$), respectively. Furthermore hyper accumulators are plants that have the ability to take up metal at levels 50-500 times more than normal plants (Cluis, 2004).

The current investigation for all Rivers has a BCF value for copper. The vegetation samples seem to be accumulating and storing copper which can be harmful to animals if consumed. The highest BCF value for copper was from the uMngeni River whereas all the other River samples have much lower BCF value (less than 1 $mg.kg^{-1}$).

5.5: Conclusion

The heavy metal content of the rivers under investigation seems to be influenced by the activities associated in and around these rivers. The presence of heavy metal in the riparian vegetation samples up to 4 metres away from the river banks indicated high possibility that the river is contaminated by these heavy metals. A proper screening of the sources of these heavy metals needs to be done. Investigations should assist in the possible reduction of heavy metal contamination of these important rivers.

CHAPTER6:

Sand mining at Umdloti River: Impact on biodiversity

6.1: Introduction:

The removal or extraction of sand directly from its natural habitat is termed sand mining. The site is often cleared by using an excavator or front end loader, removing natural vegetation, creating gravel access roads for sand transportation. Most often the sand is removed from the river beds, at times from the banks and beaches but seldom from the sea bed. The effect of such mining activities on rivers causes destruction of sensitive environments and damages to the biodiversity of the area.

Romy, (2014), indicated that, in KwaZulu Natal, the City of Durban commissioned the Council for Scientific and industrial research to carry out a cost to benefit assessment of sand mining in all 18 rivers within the municipal jurisdiction which included Tongaati and Amahlongwa and the Umvoti River. According to the assessment, the Sand Budget Analysis revealed that the rates of sand extraction exceeded the natural sediment yield of any of the river systems which resulted in a net loss of sand from the broader system. The report further stated that the upstream illegal sand mining had removed one third of all sediments in the river system.

An investigation carried out by United Nations Environmental Programme in 2014 indicated the practice of illegal sand mining as a significant part of the $200 billion global environment crime challenge. This activity of robbing the rivers for financial gain results in the destruction of the natural habitat and the reduction of biodiversity. They further open spaces for encroachment of alien species and ultimately changing the biodiversity component of the area.

The health implications from such activities are also of concern. Noise pollution and dusts emanating from the sand mining operation directly impact human health (Daniel, 2002). The carting of the sand on national and rural roads with uncovered trucks also poses a problem to daily road users and most times destruction of commuters' personal vehicles.

According to Stienberger and Kraumann, (2010), between 47 and 59 billion tons of material are mined every single year on a global phenomenon. The majority of up to 85% is sand and gravel extraction (Kraumann, 2009). Although sand mining and gravel extraction are mined more than any other material, investigation by Kraumann, *et al*. (2009), indicated that data of such is only available over recent years which indicated that it is now a concern on a global scale. The rate of extraction of sand and gravel exceeds the rate at which natural processes generate and replace these materials (Ashraf *et al*., 2011). The activities on the streams due to the mining operations are impacted such that the cycle of the ecosystem is destroyed (Ashraf *et al*., 2011). This results in the loss of potential fertile agricultural land and destruction of the riparian vegetation and potential habitat for migratory bird and other smaller animal species.

The impacts of sand mining on the physical environment may cause any of the following (Saviour, 2012)

i. the undercutting and collapse of river banks
ii. loss of adjacent land and/or structures
iii. upstream erosion as a result of an increase in channel slope and change of river velocity
iv. downstream erosion due to increased load carrying capacity of stream and downstream changes in patterns of deposition and changes in channel bed and habitat type.

Terrestrial and marine flora and fauna is impacted on directly as a result of sand mining. The recreational fishing as well as small scale agriculture is affected equally and this could lead to threats of climate change (Fortune and Mitchell, 2005). Furthermore, disposing of wastes generated by human domestic activities into river systems is disturbed by sand mining operations causing the wastes to travel further downstream (Haslam, 1990). The sand mining operation is primarily used for the construction of roads, buildings and bridges amongst many other actvities (Kondoly, 1994; Pallin, *et al*., 1994). The failure to implement protective measures will result in the total loss of biodiversity and promotions of alien invasive species in those areas being mined (Starnes, 1983; Sequiener, 1987; Naiman, 1992; Socolow, 1995; Bibly, 1998). The impact of improper aggregate mining on aquatic habitat including destabilization of spawning gravel and nursery habitat for various fish species was investigated by Meador and Layher, (1998). The investigation revealed that erosion caused by mining upstream caused major bank failure and subsequent loss of riparian vegetation of the area. The impact on the fish species from such activity cannot be measured (Waters, 1995; Unona, 2005).

Sand mining also has significant social impacts on local indigenous communities with regards to the environment they live in. The ecological impacts include erosion, landscape destruction, biodiversity loss, loss of grazing land, sand and dust pollution. The socio-economic and ecological impacts of gravel mining are responsible for development of pits in those areas being mined. These pits serve as breeding grounds for mosquitoes and the potential of spreading other water borne diseases (Musah, 2009).

According to NEMA (2004), sand mining has contributed significantly to the economic development in terms of job creation and other employment opportunities. Indigent people create small businesses by selling food and fruit to the workers at these excavation sites and use this as a means of sustaining their family. However, the excavation sites have brought in other unsavoury businesses such as prostitution, high school drop outs to go to work at the sand mining areas as well as rise in alcohol and drug abuse. Although sand mining cannot be completely stopped, government and other stake holders need to develop better laws and control measures to drive policies into practice and start conserving instead of destroying.

6.2: Methodology:

This investigation was carried out between January 2017 and July 2017. Data was collected through a combination of past investigations as well as field research. Observation investigations and community interactions were done according to Rothbauer and Paulette (2008). Structured questionnaires were distributed to government regulators, sand miners and local community members within 5km of the sampled sites. Qualitative interviews were undertaken according to Huntington, (2000). This approach allowed a more in-depth investigation into the unique experience of each interviewee.

6.3: Results and Discussion:

The percentage females to males that participated were 55:45 percentages. The ages ranged between 21 years and 65 years.

Fig 6.1: Google Earth image of sand mining operation on the Umdloti River (March 2017)

Fig 6.2: Heavy equipment used in sand mining process

Fig 6.3: Water piths formed due to mining operations

Fig 6.4: Picture showing that the Umdloti River was altered during the establishment of gravel access road

Figure 6.5: Picture showing the destruction and clearing of vegetation before mining starts

Figure 6.6: Picture showing the sand pipe sucking sand from the inner part of the river

Figure 6.7: Showing a truck on the gravel road creating dust and noise

Table 6.1: List of Plant species identified along the Umdloti River

Scientific name	Common name
Cymbopogon validus	Giant turpentine grass
Sporobolus africanus	Ratstail dropseed
Hyparrhenia tamba	Blue thatching grass
Pycreus nitidus	Leya-butle
Phoenix reclinata	Wild palm
Trema orientalis	Pigeon wood
Dichrostaychys cineria	Sickle bush
Trichilia gregeana	Natal mahogany
Erythrina lysistemon	Common coral tree
Erythrina caffra	Coast erythrina
Albizia adianthifolia	Flat crown
Brachlaena discolor	Silver oak
Ficus natalensis	Common fig
Syzygium cordatum	Water berry
Mimusops caffra	Coastal red milk wood
Strelitzia nicolai	Wild strelitzia
Arundo donax	Spanish reed
Melia azedarach	Syringa
Arundo donax	Spanish reed
Cardiospermum grandiflora	Balloon vine
Casuarina sp	Casuarina

Table 6.2: List of insects noted

Scientific name	Common name
Anisoptera sp	Dragon flies
Zygoptera sp	May flies

Plecoptera sp	Stone flies
Anopheles sp	mosquito

Table 6.3: Knowledge of regulations of sand mining of participants

Summative question	YES	NO
Knowledge of Regulations	66	34
Knowledge of application process	32	68
Possession of valid permit	33	67

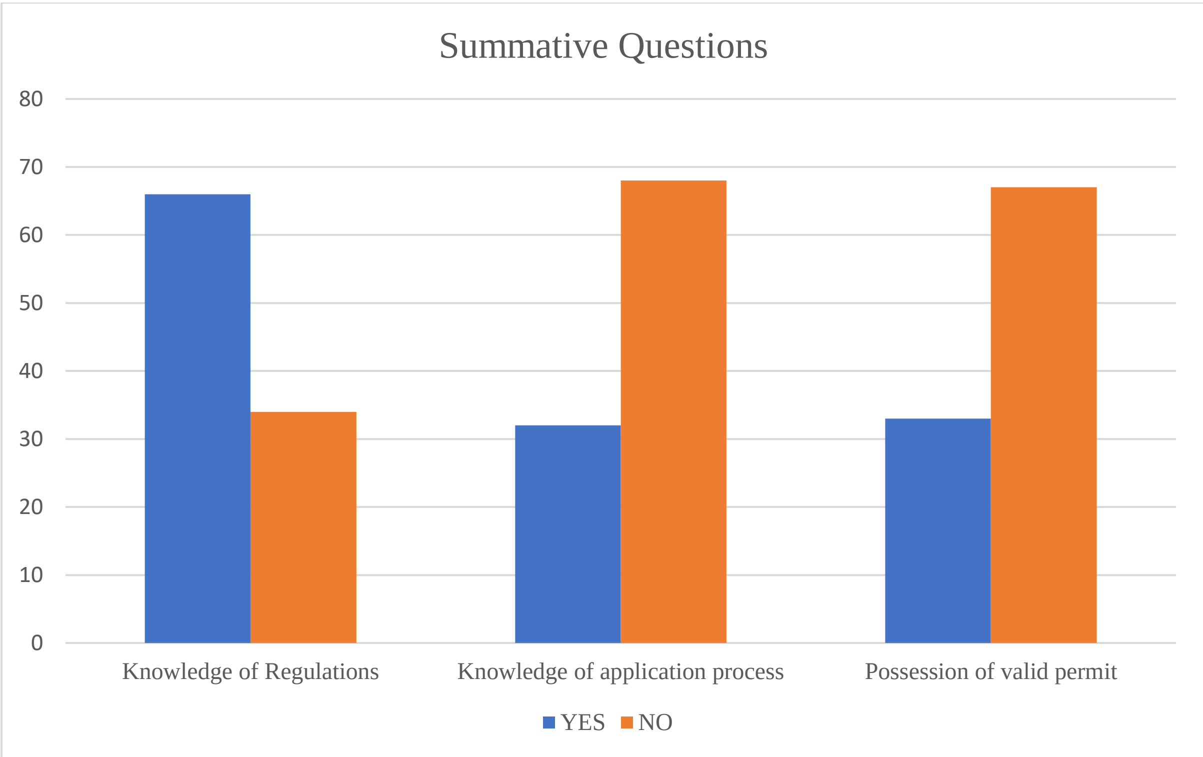

Fig 6.8: Graph of summative questions

Table 6.4: Number of tons of sand extracted

Miner	Quantity (tons)						
	Jan	Feb	March	April	May	June	July
Miner 1	40	60	60	50	50	40	40
Miner 2	80	110	90	70	160	150	120
Miner 3	30	50	30	40	30	30	30
Total per month	150	220	180	160	240	220	190

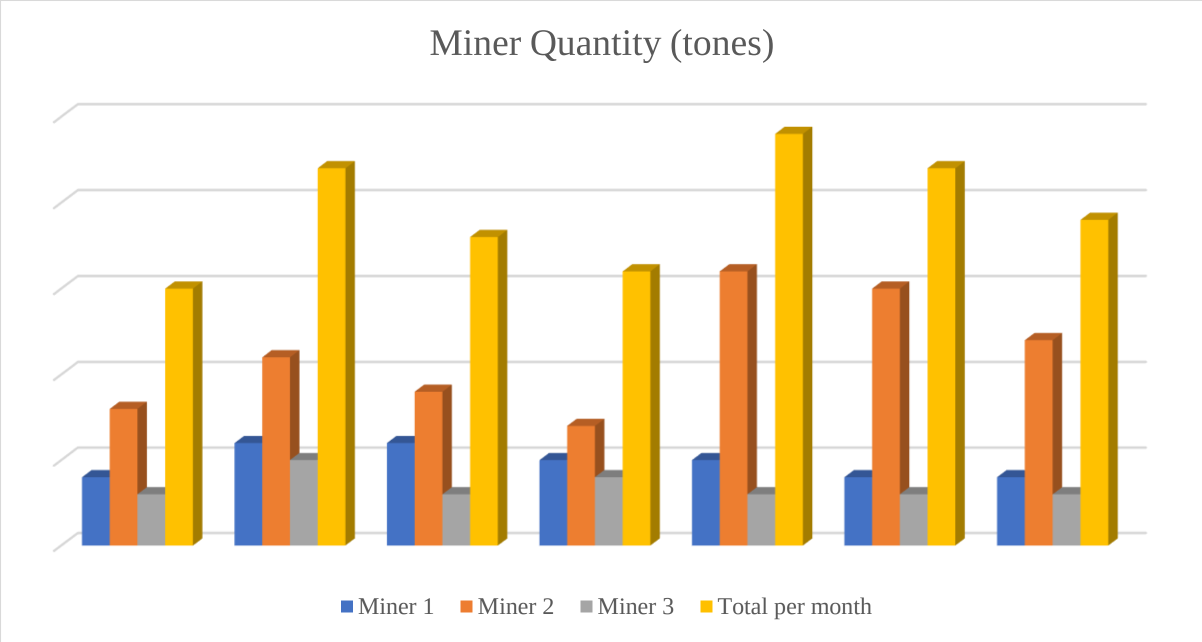

Fig. 6.9: Miners usage per tons

All the miners in mining operations were involved because of economic gains and job creation with the ages ranging from 21 to 65 years. The younger individuals indicated that their inability to secure employment elsewhere were prompted to get involved in sand mining to support their young families. Only 66% of the miners had knowledge of the regulations associated with sand mining and 67% did not have a permit to undertake such activities (Table 6.3, Fig 6.9). Hence the 67% miners are doing this operation illegally. There were more females than males that were labourers in the sand mining operations. The total tonnage taken over a month was between 150 tons and 240 tons (Table 6.4). Many of the miners indicated that the tonnage extracted was reliant on the need by purchasing individuals.

Majority to the disturbed areas showed a drastic increase in alien species of vegetations while undisturbed areas are still maintaining their natural vegetation. The fly species was common amongst disturbed and undisturbed sites. Once the site is disturbed, the place becomes easily available for alien species to thrive. This would over shadow the pioneer species and ultimately result in the loss of biodiversity.

According to Musah (2009), mining activities significantly contribute to erosion and loss of flora and fauna in and around the mining sites. The mining sites become so disturbed that most of the indigenous vegetation that are lost will not be able to recover at the rate it was being destroyed. It was further established that the miners do not preserve the top soil of mining areas, hence creating an almost difficult rehabilitation process once mining operation has moved onto other parts of the river (Musah, 2009).

The Department of Mineral and Resources is the body responsible for the control of sand mining operations. However, there seem to be no control measures put into place. Areas of sand mining should be mapped out and recorded for future purposes and current mining operations should not go back to the previously mined areas. The knowledge provided by the respondents alludes to the above-mentioned and in many ways agrees with the control measures that needs to be instilled for preservation and conservation of the river system. The frustrations expressed by many applicants to the Department of Mineral and Resources for permits is undeniably high as only three permits were issued in response to applications from over 20 applicants.

6.4: Conclusion:

The investigation into sand mining of the Umdloti River is of concern as it poses a threat to the biodiversity of the area. The disturbed areas have lost their biodiversity in totality and have made way for alien species encroaching into the area at a rapid rate. Regulatory bodies need to be more assertive in control measures to prevent illegal mining or promote awareness of the potential impacts of illegal sand mining of rivers. There should be more frequent monitoring by the regulatory bodies to protect this natural resource of our country, South Africa.

6.5: Recommendations

All the three spheres of government (Local, Provincial and National) should be mandated to regulate sand mining activities. Urgent integrated environmental assessments and ongoing monitoring programmes need to be implemented. There is a great need to increase public awareness and participation on the sand mining operations and how it affects their livelihoods.

CHAPTER 7

Government policies that impacts river conservation and people's perception and knowledge of the policies

7.1 Introduction

Rivers hold one of the most important commodities for the survival of the planets. The White paper on National water policy in South Africa describes water as colourless, tasteless and odourless. Its most important property being its ability to dissolve other substances. We in South Africa do not see water that way. For us, water is a basic human right, water is the origin of all things - the giver of life.

Water Quality Management Policies and Strategies for South Africa recognise that the existing Water Quality Management (WQM) policy is outdated (Water Quality Management Policies and Strategies in the RSA in 1991 and the Resource Directed Management of Water Quality in 2006) and is in dire need of revision. There should be consideration for changes in governance at all spheres of government (Local, Provincial and National). The changes should incoporate business, public and private sectors. All policies that are needed for conserving this precious commodity need major revision to provide a significant platform for the development of new strategies and policies. It is well known that WQM is a core element of national water resource management policy which reflects the National Water Resource Strategy (NWRS) (Version 2), the resources and political emphasis housing the WQM is insufficient to support the necessary management protocols. Hence a renewed approach towards WQM is critical in order to manage the resources sustainably.

This chapter outlines some of the policies that govern the management of our natural resource as well as people's perception and knowledge of the policies that are present for effective management and control of the riverine body.

7.2 Methodology

Structured questionnaire were administered to various stakeholders including indigent people who reside in squatter developments along the rivers under investigation. Similar questions were directed to those in government. This was done to ascertain the extent of the knowledge of the policies amongst the public sector.

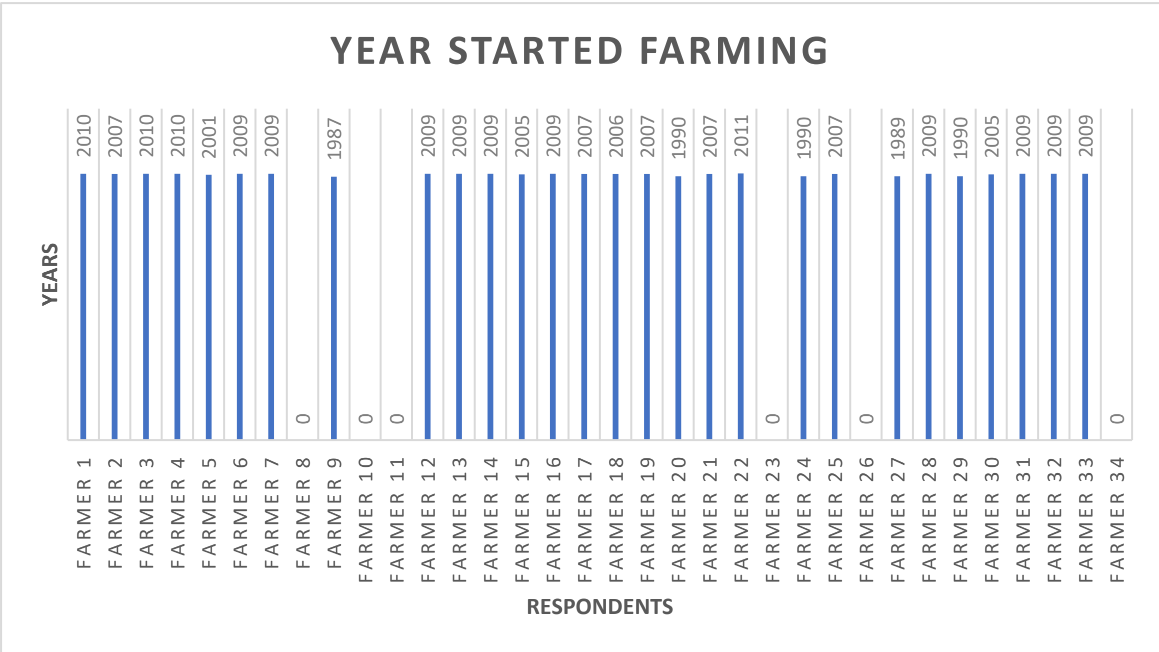

Fig 7.1: Graph showing when the small scale farmers started. NB: Six Small Farmers did not supply information about when they started first started farming n=34.

7.3 Results and Discussion:

7.3.1 People's perception: Small scale farmers and indigents

The survey provided a suitable platform of understanding how long farmers and other indigent folks practiced farming along the rivers under investigation. From the survey, 91% of respondents grew up on farm they currently own. There were 59% of respondents who said love of nature was the main reason for starting a farm and 41% cited family responsibility. It was also shown that 97% of respondents noted differences between the current state of the farm, and the old version of farming when they were still a kid such as access to electricity and adoption of new technology. Furthermore 100% of respondents cited a change of business model in respect to farming practices. The use of chemicals and technological advancements such as machinery, genetics or chemicals affected 97% of respondents, with regards to competition with other farms. On the question of livelihood, 44% of respondents viewed farming as business while 44% viewed it both as a business and lifestyle choice. Maize was being cited as a main crop by 71% and sugarcane was cited as the most profitable crop by 97% of the participants. While the use of chemicals was cited by 44% of respondents and 41% of respondents cited that farming as their only source of income, 59% have other sources of income. As to environmental awareness, 83% of respondents cited that their farms are environmentally friendly and 76% of respondents stated that their use of pesticides and herbicides affected the river/streams nearby whereas 62% of the respondents cited that they did not implement any strategies to deal with lack of biodiversity on the river/streams close to their farms. Only 50% of the respondents stated that they have an idea about sustainable water usage.

7.3.2 Freshwater management systems – Major water pollutants, key policies and water management

The main contributors to water pollution in South Africa include:

1. Salinization of freshwater resources which contributes to water pollution. In coastal areas, this phenomenon is caused by excessive groundwater pumping which leads to seawater being drawn into wells and aquifers. Street paving's in urban and suburban areas increases salt concentration in freshwater systems – salts are transported into freshwater systems through saline runoff's during floods and storms.

2. Eutrophication which causes an increase in the number of nutrients present in freshwater systems. These nutrients (e.g. phosphorus and nitrates) cause a shift on the composition and function of the natural ecosystem. Toxic metabolites and other odour-causing compounds form complicates water treatment processes.

3. The introduction of enteric bacteria and parasites into freshwater systems caused by anthropogenic activities contributes to decline of microbiological water quality standards. These organisms enter the local water bodies through partially treated sewage effluents, wash-off from insufficient sanitation and leachate from waste disposal networks.

4. Industrial by-products which are introduced into the freshwater system in the form of trace metals and synthetic organic pollutants since the removal of these compounds with conventional water treatment technologies is difficult.. The presence of these elements is a public health concern to both humans and the aquatic ecosystems.

5. The emissions of heavy metals such as mercury into groundwater systems. Mercury is introduced into the river systems during the process of extracting gold by illegal miners.

7.4 Key policies and water management systems

1. The National Environmental Management Act (No. 107 of 1998), puts in place government structures for cooperative governance among environmental authorities, legally obligates the principles in the White Paper on Environmental Management Policy for South Africa and makes provisions for the control and remediation of environmental impacts and degradation.

2. White Paper on National Water Policy (1997) puts emphasis on the management of water resources for meeting basic human needs, for enterprise development and recreational use. It also includes public works programmes such as Working for Water Programme and Integrated Catchment Management. The basic principle of the policy is to provide water resources to all South African citizens by promoting the right to basic amount of clean and accessible water to all.

3. The National Water Act (No. 36 of 1998) provides the department of water and sanitation with the responsibility of ensuring that water quantity and quality aspects of pollution and waste management on a national level are up to standards. The act creates a legal framework for the management of water resources which includes rivers, streams, dams and groundwater.

4. The Environmental Conservation Act (No. 73 of 1989): provides permits for landfill sites including the development of guidelines and applicable standards.

5. The water Service Act (No. 108 of 1997): regulates water service provision for local governments. This includes drinking water and sanitation services supplied by municipalities to households and other municipal users.

6. The Free Basic Water Policy, adopted in February 2001 by the national government, targets the water needs of the most impoverished South African citizens by making sure that each household has a free minimum quantity of potable water. According to this policy, each household is entitled to six kilolitres per month. This is based on an assumption that each individual person needs 25 litres of water per day. The amount for each household across the board is same for every citizen, irrespective of different socio-economic inequalities observed in South African households.

7. The Integrated Pollution and Waste Management policy, applies to all government institutions, society and to all activities that impact on pollution and waste management. One of the fundamental approaches of this policy is to prevent pollution, minimise waste and to control and remediate impacts. The management of waste is implemented in a holistic and integrated manner and extends over the entire waste cycle, from "cradle-to-grave", including the generation, storage, collection, transportation, treatment and final disposal of waste.

8. The National Water Policy (1996) and the National Water Act emphasize the need to protect aquatic ecosystems in order to allow for sustainable achievement of social and economic benefits from these systems. This essentially requires a fine balance between protecting rivers and achieving economic development.

9. The National Water Conservation and Water Demand Management (WC/DW) strategy, promotes efficient and sustainable use of water from all different spheres of the society, (e.g. the private and the public sectors).

10. The SADC Regional Water Policy and Regional Water Strategy (RWS) policies are used as guiding instrument for water resource management practices, by member states. These policies collectively subscribe to the principles of Integrated Water

Resource Management. The IWRM is defined as a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of the important ecosystems.

7.4.1 Bill of Rights

According to section 24(a), of the Environmental Bill of Rights, everyone has the right to an environment that is not harmful to their health or well-being, and to have an environment protected for current and future generations. The South African Department of Environmental Affairs is mandated the following

1. to regulate sustainable growth and development
2. promote conservation of natural resources
3. protect and improve the quality and safety of the environment
4. ensure strict systems and services for marine, coastal and terrestrial resources
5. prevent and limit pollution and waste, implement robust environmental authorisations and to improve air and atmospheric quality (DEA, 2014).

The report of DEAT (2002) makes mention of environmental rights that relates to clean environments are connected to health and wellness of the South African citizens. Debates around environmental protection have gained substance in recent years on various International forums. This has been attributed to issues such as global warming, ozone depletion and biodiversity that are beginning to show their negative effects globally (Feris and Tladi, 2003). In South Africa, a healthy environment is constituted as one of the main basic human rights. In contrast, a lot of countries around the world do not have policies that are aligned to protect their environments. This piece of legislation thus makes South Africa a privileged country (DEA, 2014) but not limiting South Africa from any environmental issues since the pressure to improve the quality of life for both the present and future generations through sustainable development is essential. This is a global phenomenon of which South Africa shares as well (DEAT, 2002).

Local government plays a significant role in the protection of natural resources and support of effective environmental governance. The changes on the legislative framework both at local and national government cause a lack of clarity and integration between the three main pillars of governance: National, Provincial and Local government (Middleton *et al.*, 2011). In South

Africa, after 20 years of democracy there are still policy makers who are struggling to define a clear role of local government departments and their responsibility for environmental protection (Du Plessis, 2015). The South African constitution affords environmental rights to its citizens. However, it fails to implement clear roles that will assist local government departments to fulfil that right to its fullest potential (Du Plessis, 2015).

The main drivers of sustainable development include proper sustainability and prevention of exploitation of natural resources. However consideration for people that inhabits the natural environment as well as the well-being of such people should be rated by the quality of their living standards which is crucial. The South African government should take this matter into cognisance as it is stipulated in the Environmental Bill of Rights. Over the years, the South Africa legislator has done a lot of work on the improvement of the environmental laws, and this success is attributed to the constitutional amendments made to the Bill of Rights, number 108 of 1996 (Kotze, 2003).

7.4.2: Constitutional Courts

One of the critical aspects that the South African Constitutional Court needs to pay special attention to is to ensure that the law interpretations between the governing party is in sync with law institutions to eradicate confusions with regards to implementation and abiding by the rules and regulations. This would bring matters pertaining to socio-economic development and conservation to be in line with the sustainable development goals (Kotze, 2003).

7.4.3 The policy on Sustainable Coastal Development in South Africa

This policy is currently being developed into law and recognizes that estuaries are key coastal resources which require active management and conservation to maintain their integrity. Estuaries offer a wide range of benefits such as flood control, supply of raw material for subsistence and provide nursery for juvenile fish. The aims and objective of the policy are to maintain the rich biodiversity found in South African estuaries. This will ultimately halt or stop coastal developments which are destructive to estuaries due to anthropogenic activities (DEA, 2013). Severe degradation is often related to unsustainable coastal developments of which if not regulated, the country will face danger of losing its natural resources permanently. Destruction of plants and animals species reliant on estuaries for shelter will be severely affected. With this in mind there should be a balance between economic growth and sustainable development goals (OEDP-IMCPI, 2003).

7.4.4: The White Paper

The white paper on sustainable coastal development alludes to the various development taking place on South African coastlines should be ecological, social and economically sustainable (DEAT, 2006).

The rationale behind the implementation of the white paper for sustainable coastal development is the preservation or conservation of diversity taking into consideration longevity (Coast Care, 2000). The National Strategic Biodiversity Assessment indicates that 28% of South African estuaries are considered to be in excellent condition, 31% in good condition, 25% in a fair condition and 15% in a poor state (Coastal Zone, 2011). According to the DEA (2013) report, there are about 300 functional estuaries in South Africa across a coastline of about $^{\pm}$3200 km. In 2011, National Biodiversity Assessment Survey indicated that 43% of estuary ecosystem types are threatened which accounts for about 79% of South African estuarine areas. There are only 33% protected estuaries and approximately 59% which lacks protection (DEA, 2013). The unprotected estuaries are prone to pollutants from coastal developments which affects water quality and bioaccumulation of toxins in marine species. The main contributors of pollutants are industrial and domestic effluents from residential areas as well as agricultural practices posing a threat to marine life. An indicator species, rock mussel, is closely monitored by the Mussel Watch Programme of the DEAT for pollution in marine coastal waters. Any changes in heavy metal concentration in mussels are used as indicators (Coastal Zone, 2011).

The developments associated with South African coastlines are aggregated towards major harbours and cities. Pollutants associated with these regions originate from the spillages of sewage waste and industrial runoff. Notwithstanding this, the South African coastline still has approximately 63 sewage spillages placing human life and biota at high risks in terms of health issues. Developments also contribute to habitat transformation often observed near Estuary (OEDP-IMCPI, 2003). Upper reaches of rivers are often affected by agricultural waste by-products and urban developments which would ultimately end up in estuary degradation.

7.4.5: The Sea Shore Act (SSA)

This act regulates all activities in the coastal intertidal zone including any activity in an estuary below the high tide mark which is also covered by the Environmental Conservation Act. The SSA focused on high-water marks which include the highest point reached by coastal waters but excludes abnormal flood lines, storms and estuaries that are close to the sea. The Environmental Conservation Act is inclusive of both the conservation of land and coastal resources (The Presidency, 2011). The SSA (Act No.21 of 1935) comprises of the Sea Birds and Seals Protection (Act No.46 of 1973). The act prohibits people from setting foot on island and from shooting or capturing sea bird or seal that belong to the fishing zone of the Republic of South Africa between the low-water mark and high water-mark (Government Notices, 1974).

The Sea Shore Act further legislate that people who builds structures on protected seashore lines are liable for costs incurred for removing the structures when caught. Moreover, individuals could face prosecution and if found guilty, a fine or imprisonment for a period not exceeding two years can be sanctioned (State Presidents Office, 1994).

Section 2 of The Sea-Shore Act number 21 of 1935, affords the state president the ownership of sea-shore and the sea. However, the portion of land which has already been designated as a protected area remains fielded from ownership by the president. Thus, a minister has a right to exercise section 3, which triggers the sea-shores and the sea to be let go for developments deemed necessary by the minister (DEA, 1935).

7.4.6: Environmental Conservation Act

Development in South Africa is covered by the Environmental Conservation Act (ECA) which requires through the Environmental Impact Assessment Regulations that an environmental assessment report be provided for almost any development in/or adjacent to an estuary provided permission for such development has been obtained from the relevant authorities. The ECA ensures control of activities that are deemed dangerous to the environment and further mandates a Minister to publish activities on the government gazette, which are on his/her opinion potentially dangerous to the environment. Activities that pose a threat to protected area include land use and transformation, water use and disposal, resource removal including natural living resources, resource renewal, agricultural processes, industrial processes, transportation, energy generation and distribution, waste and sewage disposal, chemical treatments and recreational activities (DEAT, 1989).

The ECA makes a directive to competent authority with regards to them declaring on the government gazette about areas that they have cited as limited development areas. Developments in these areas are only permitted if permission is granted by the competent authority via relevant application and documentation route (DEAT, 1989).

7.4.7: The Environmental Impact Assessment

The Environmental Impact Assessment (EIA) is a fundamental procedure for assessing specific types of developments. There are five main sectors identified which require special treatment. These are Agricultural and industrial projects, energy projects, large scale property developments, social infrastructure and housing projects and linear developments. These sectors have been chosen because of their locations require large portions of land on the outskirts of residential areas and hosting of other activities associated with rivers and estuaries.

7.4.8: The National Management Act

The National Environmental Management Act (EMA) includes the provision that allows members of the public to take legal action in the public interest to protect the environment. This includes action against government departments to force them to implement laws. Minister of Environmental Affairs, Edna Molewa, published a consolidated environmental implementation and management plan which was initiated according to section 15(5) of the National Environmental Management Act, 1998. The plan mandates the Department of Environmental Affairs and other government institutions responsible for the well-being of the environment to prepare environmental implementation plans (EIPs) and/or environmental management plans (EMPs) (DEA, 2016).

The Department of Environmental Affairs, Environmental Implementation and Management Plan outline the following main objectives:

a) To coordinate and harmonise the environmental policies, plans, programmes and decisions.
b) To initiate the principle of cooperative government included in Chapter 3 of the South African Constitution.
c) To secure environmental protection across the country
d) To prevent unreasonable actions by provinces in respect of the environment that are prejudicial to the economic or health interests of other provinces or the country as whole.
e) To allow the Minister to monitor the achievement, promotion, and protection of sustainable environment (DEA, 2016).

With regards to this, the National Environmental Management Act is driven by strong regulatory obligations directed to those who are in charge in governance. This Act over shadows many other regulatory laws prescribed for other environmental laws. Public participation can be exercised by South African on matters related to environmental laws deemed by the public to be important and urgent attention coming from the government departments (DEA, 2016).

7.4.9: The Marine Living Resource Act

The Marine Living Resource Act regulates all activities associated with that of living resources in estuaries including bait collection, commercial, recreational and subsistence fishing and the harvesting of estuarine plant species (DEAT, 2008).

The Department of Environmental Affairs and Tourism made regulations on the Stilbaai Marine Protected Area. The regulations were made under Section 77(2)(x)(i) of the Marine Living Resources Act, No. 18 of 1998 by the Minister of Environmental Affairs and Tourism, Marthinus Van Schalkwyk. The act aimed to regulate the following occurrences:

a) To protect and conserve the coastal environmental and marine living resources that is found in and around the marine protected area.
b) To sustain and protect the reproductive capacity of exploited fish including shell fish so as to allow their populations to recover and to contribute to the replenishment of adjacent areas.

c) To protect the nursery of the Goukou estuary and the recruitment of estuarine-dependent fish into marine fisheries and
d) To control other activities in the Marine Protected Area to reduce the risks of habitat degradation and to preserve the viewers, which have archaeological and cultural significance (DEAT, 2008).

The fishery industry is regulated by the Marine Living Resource Act to ensure that the ecological resources derived from the marine ecosystems are protected and at the same time ensuring that the economic value of the oceans economy is properly utilised for socio-economic growth and reduction of poverty, especially on small-scale fishing communities. This framework will afford small-scale fishery industry the opportunity to close the gap that exists between them and the major commercial fishers economically (DEAT, 2008).

7.4.10: The Conservation of Agricultural Resource Act

The Conservation of Agricultural Resource Act ensures proper steps are taken to guarantee the conservation of soil and water in agricultural practices. Various control measures employed by farmers should be implemented to preserve the agricultural resources. These are as follows:

1. cultivation of virgin soil
2. the utilization and protection of land which is cultivated and irrigated
3. the prevention of water-logging or salination of land
4. the utilization and protection of vleis, marshes, water sponges, water courses and water sources
5. the regulation of the flow pattern of run-off water
6. the utilization and protection of the vegetation, the grazing capacity of veld, expressed as an area of veld per large stock unit
7. the maximum number and the kind of animals which may be kept on veld
8. the prevention and control of veld fires
9. the utilization and protection of veld which is burned
10. the control of weeds and invader plants, the restoration of eroded land or land which is otherwise disturbed
11. the protection of water sources against pollution account of farming practices and

12. the construction, maintenance, alteration or removal of soil conservation works or other structures on land. (DA, 1984).

Cultivation of agricultural land is regulated by three main legislative acts namely; Conservation of Agricultural Resource Act No.43 of 1983, National Environmental Management Act No 107 of 1998 and Environmental Impact Assessment Regulations 2014. The main objectives of these acts are directed to conservation of soil and water resources. Regulatory bodies monitor activities and provide permits to any individual who wants to cultivate agricultural land in South Africa. The decision is recorded as per the National Environmental Management Act before a permit is issued. However, developments greater than $300m^2$ requires proper authorisation from the Environmental Impact Assessment Act of 2014 (Botha, 2016).

Sustaining the soil structure is important in agriculture to ensure a continuous supply of agricultural products. The impact of agricultural input used during agricultural practices is assessed during the Environmental Impact Assessment practices. The Agricultural Resource Act presides over the use of water and soil resources, in relation to contamination caused by agricultural inputs. It also protects against the exploitation of these resources, an occurrence prevalent during major agricultural developments (Botha, 2016; DA, 1984).

7.4.11: The National Water Act

The National Water Act recognizes that estuary is a water user and that provision for such needs to be made so that sufficient freshwater flow into estuaries for sustainable ecological functions. Furthermore, the Act recognises that protection of freshwater resources is paramount.

7.4.12: The South African Water Act

The South African Water Act of 1998 protects the rights of water bodies' survival. There seem to be some flaws in the implementation of the laws pertaining to this act which leaves integral ecosystems open to exploitation. Recently, it has been noted that there have been some work done by the water bodies in an effort to protect some of South Africa's sensitive estuaries. Estuaries form a conduit between marine and freshwater environments, which means they are complex, dynamic and productive ecosystems. Estuarine systems provide erosion control, provide food, support of fish nurseries and provision of recreation and tourism opportunities making them the most extensively utilised and threatened ecosystems worldwide. The National Water Act seeks to control and protect all negative activities that are potentially detrimental to estuarine environments (NMMU, 2016).

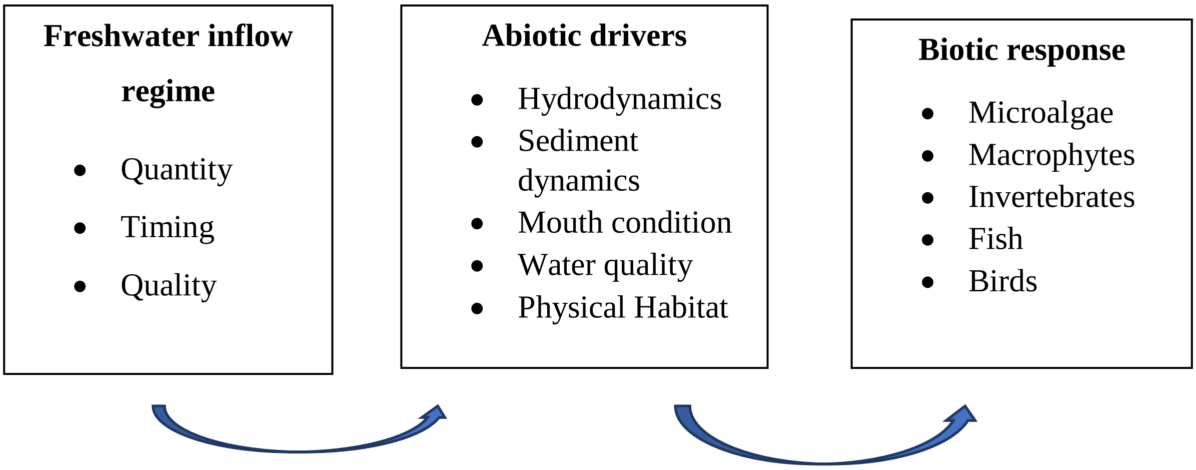

Figure 7.1: Conceptual model of freshwater inflow effects on estuaries (NMMU, 2016)

There are strong correlations between the effects of human activities and functioning of estuaries with reference to water quality and ecological integrity. The effects are not only felt within the estuarine environment but throughout its entire upstream catchment.

The flow of freshwater into estuaries is important and the physical aspects of water entering the estuaries require proper monitoring and evaluation in terms of the quantity, timing and quality (fig 7.1). The chemical and sediment components of the freshwater inflow are critical as they may affect biodiversity of species present on the estuary including microalgae, macrophytes, benthic invertebrates, fish species, and birds (NMMU, 2016).

7.4.13: The National Forest Act

The National Forest Act considers the use of indigenous forest resources in and around estuaries and covers the protection of Mangrove forests (DAFF, 2017).

The purpose of the National Forest Act is to

1. Ensure sustainable management and development of forests.
2. Set strict conditions and structural reforms directed at state forests.
3. Put in place measures aimed at protecting certain forests and trees.
4. Advocate for the sustainable use of forests for environmental, economic, educational, recreational, cultural, health, and spiritual purposes.
5. Promote community forests, and
6. Ensure greater participation in all aspects of forestry and the forest products industry by persons disadvantaged by unfair discrimination (DF, 1998).

7.4.14: The Minerals Act

The Minerals Act requires that mining, quarrying or sand-mining are subjects to an environmental report inclusive of rehabilitation measures. This is done prior to commencement and that the activity is permitted by the Department of Mineral and Energy and is regulated by this body. Permission needs be granted first before mining operation can start. A positive trait is that mining companies need to assess the environment, learn about the local community and consult with everyone who will be affected by the proposed mining before any permission can be granted.

Four permits are required before a company starts mining;

1. A mining or prospecting right.
2. An authorised environmental management programme or plan
3. A water use licence, and
4. An evidence of environmental authorisation (CFER, 2013).

The Minerals Act protects local communities against major mining consortiums especially for the mineral extraction and subsequent dangerous contaminants from the chemicals used and extracted that can cause harm on local communities and the natural environment. The monitoring activities play a vital role in this regard because they ensure that all the dangers that can arise through the building or implementation of new mining plants are identifed and mitigated if necessary(CFER, 2013).

7.4.15: The Municipal Systems Act

The Municipal Systems Act requires that municipalities establish Integrated Development Plans (IDP's). These plans need to include spatial development frameworks, land-use management systems, and environmental management plans. These all require that potential environment of development/Land-use options be taken into consideration. The IDP is a process whereby municipalities formulate a strategic development plan for a five-year cycle. The Municipal Act of 2000 requires that all municipalities (Metropolitan Municipalities, District Municipalities and Local Municipalities) prepare an Integrated Development Planning Process to produce integrated development plans. The IDP targets municipal management, allied agencies of the municipality, corporate service providers, NGOs and the local private sector within the boundaries of the municipality (DPLG, 2000).

Since the dawn of democracy, there were radical structural changes on the local government council's management practices. The emphasis was placed on developmental role, which is defined as a commitment to work with citizens to find sustainable ways to meet their social, economic and material needs to improve the quality of their lives. Furthermore, local authorities were mandated to pay special attention to developmental policies and legislation and implementation thereof. The end goal of the local municipalities was to create a planning process directed at redressing the imbalances of the past caused by apartheid era in South Africa (Tshwane IDP, 2006).

7.5 Conclusion:

Although many policies exist in fresh water and marine management, the policies are not effectively implemented, managed and monitored. There needs to be stricter measures meted out to transgressors of these policies. Fines and imprisonment should be implemented. Employment of more control officers and the need to enforce the law on transgressors need be undertaken. Education of the farmers on the existent policies need be a priority. From the previous chapter, the sand mining operations should be addressed to prevent the illegal sand miners from operating.

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